JANUARY 1959
VOL. 2 • NO. 1

- Matthei — Solid State Receivers
- Southworth — Using Smith Chart - I
- Süsskind — Microwave Education
- Microwave Associates Company Profile
- Ernst Weber — Biography

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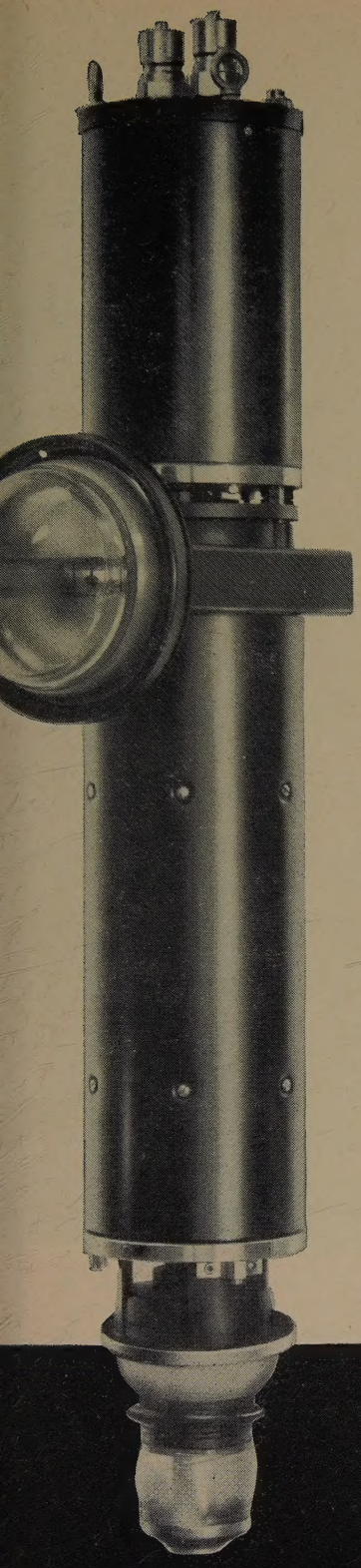

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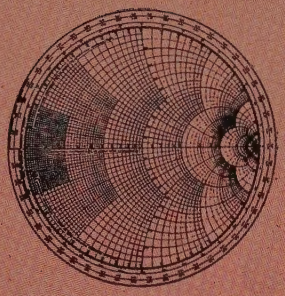

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COVER PICTURE

The picture on the cover is a parametric amplifier developed by Irving Goldstein of the Raytheon Manufacturing Company. The characteristics of this amplifier are as follows:

f_{signal}	= 2670MC	= 1585MC	= 3000MC
f_{pump}	= 5365MC	= 5355MC	= 5600MC
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BW	= 2.5MC	= 1MC	= .8MC
NF	= 2.9db	= 6mw	= 6mw
Pump Power	= 6mw		

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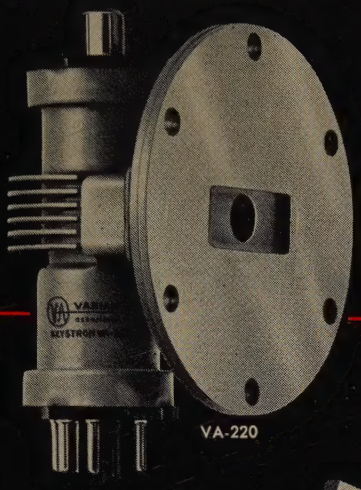

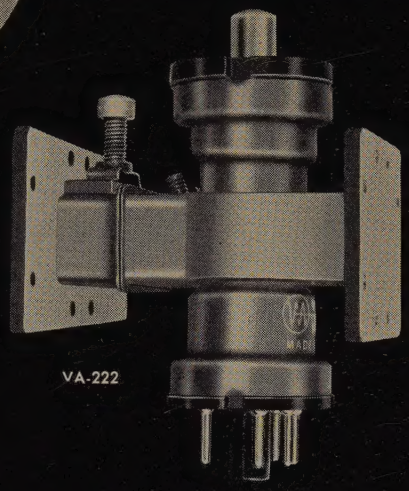

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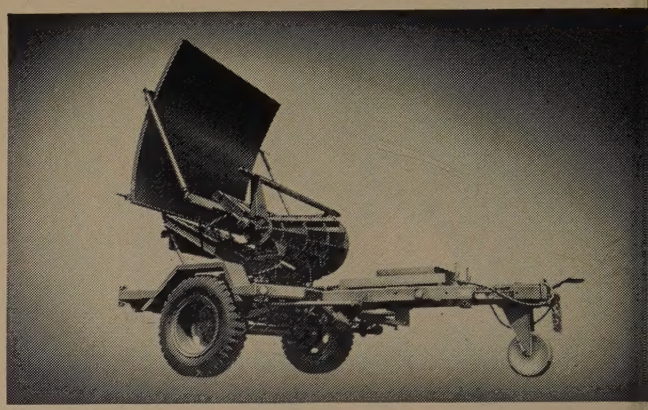

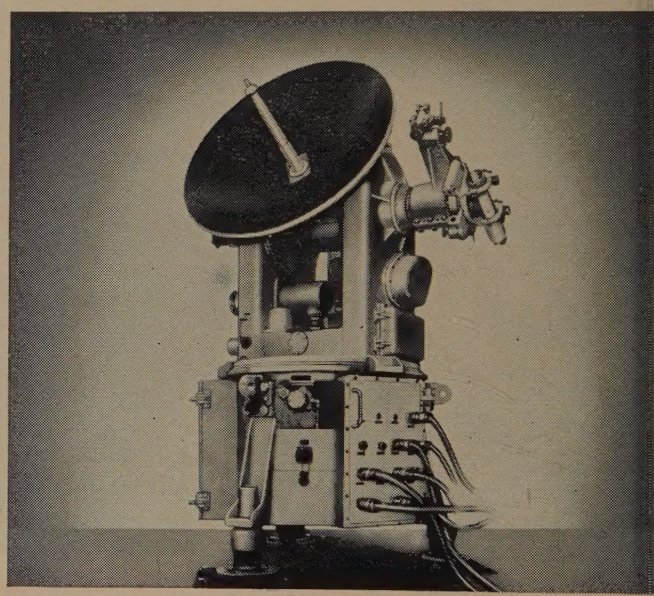

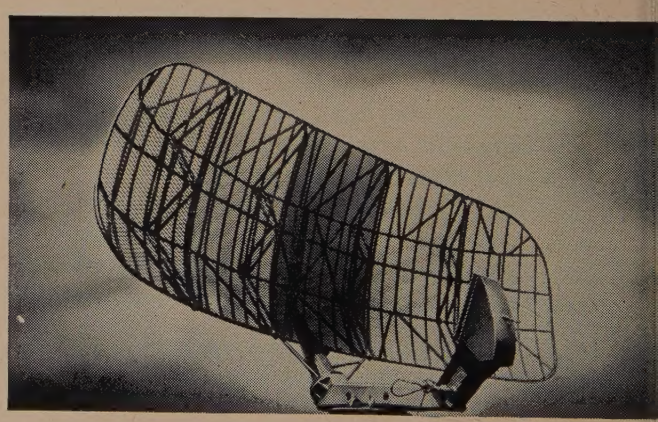

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The research reported in this document was supported jointly by the Army, Navy and Air Force under contract with the Massachusetts Institute of Technology.

MICROWAVES AND THE SOLID STATE

By BENJAMIN LAX

STAFF MEMBER, MIT LINCOLN LABORATORY

The tremendous impact which the solid state sciences ve had on the microwave art is a consequence of the imate relation between pure and applied research. rhaps the first significant contribution of the solid te was during the war when microwave detectors using rmanium and silicon were developed. These whisker- e crystals are still in use today, not only as detectors, t as harmonic generators at millimeter and submilli- ter waves. The microwave engineer has benefitted m the efforts of the research scientist. In turn, the orts of microwave engineers, both in industry and in oratories, have provided the scientist with modern crowave tools enabling him to get off to a flying start investigating the fundamental properties of solids.

The first exploitation of the new microwave tools s paramagnetic resonance, which was discovered by voisky in 1945. This phenomenon has been exten- ely investigated since by various groups in America d Europe, particularly at Oxford. The cycle was again mpleted when what appeared to be a purely academic earch field resulted in the evolution of the solid state ser pioneered by Townes, Bloembergen and others. us this low noise amplifier has been born as a result the happy marriage between the products of the mi- wave engineer and the solid state physicist.

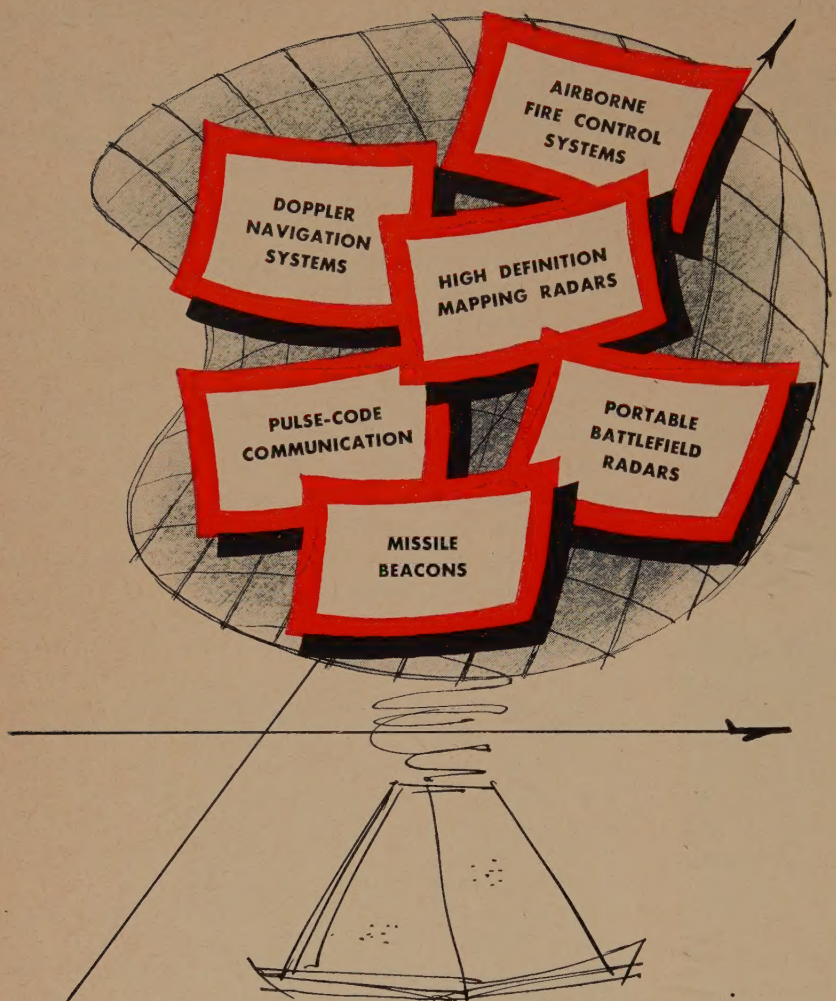
After the discovery of paramagnetic resonance it was ly logical that microwaves be used to study ferro- gnetic resonance. The discovery of the resonance by iffith and subsequent theoretical developments by ttel and Polder stimulated the extension of this work ferrites. It was not long afterwards that the inven- n of nonreciprocal devices, such as circulators by gan, gave the microwave people a new and fascinat- toy. Devices such as circulators, isolators and phase fters, which have evolved as a consequence, have ad- nced systems both in the field and the laboratory.

It was only natural that the practical developments in ferrite field gave rise to increased support of funda- ntal research in ferromagnetic resonance. The fun- mental investigations of the nonlinear behavior of romagnetic resonance led Suhl to the timely inven- n of the ferromagnetic amplifier. This device was utiful in conception. Its operation in principle has en adequately demonstrated by the people at Bell lephone Laboratories and its theoretical low noise abilities even at room temperatures makes it an at- ctive device. However, the sophistication and trou- s encountered with instabilities in ferrites, which pre- t accurate noise measurements, do not appear to make s device a practical one. These very instabilities ich are so troublesome have possibilities as power iters, and such by-products of high power investiga- ns in ferrite may prove to be more practical than the romagnetic amplifiers themselves. Other promising sibilities of the nonlinear properties of ferrites and garnets appear to be the generation and detection of millimeter waves.

Whether the ferromagnetic amplifier stimulated the present vigorous activity on parametric amplifiers or whether it was a pure coincidence, it is still interesting to note that the equivalent circuits of the former featured resonant circuits with variable capacitance. From the engineering viewpoint, the simplicity of the parametric amplifier which uses the solid state silicon diode or its equivalent makes it an extremely attractive device and may relegate the maser to secondary importance. Perhaps for some applications this is true, but it would be a mistake to assume that this is so for all systems. Just as in the case of the transistor vs. the vacuum tube, each had its place and each complemented the other. In the case of parametric amplifiers vs. masers, the situation will be analogous. Perhaps at the lower microwave frequencies the parametric amplifier will be king, but at higher frequencies where extremely low noise will be required in operating certain radio astronomy and radar systems and in the millimeter region, the maser has a bright future. Of course, neither has been fully tested in operation as yet. Consequently, the future of each is still controversial.

This, of course, is an incomplete and inadequate review of the profitable interaction between solid state physics and microwave development. Nevertheless, the examples serve to indicate that the future holds many exciting surprises which may result from such interaction. New phenomena have been and are being discovered and are yet to be exploited. Cyclotron resonance in semiconductors is only five years old and already the literature is full of proposals and dreams for generating coherent microwaves, millimeter waves and infrared radiation through the use of this phenomenon. So far, success has been meager, but it is the belief of the writer that as we gain more and more understanding of the fundamental processes in this and related phenomena, practical accomplishments will be realized.

Optical and magneto-optic effects being observed in solids of all kinds such as paramagnetics, ferri- and antiferromagnetics, semiconductors, and their interrelation to microwave and millimeter radiation cast their shadow of hope still further into the future. The availability of very high magnetic fields which permit the observation of resonance in the millimeter and submillimeter region promise new experimental developments in these spectral regions. However, the research scientist can benefit tremendously by the extension of existing microwave techniques to the development of components, oscillators and detectors into the millimeter and sub-millimeter region. Here is an area where interplay between available know-how and recent developments in the solid state can be effectively applied to extend our knowledge into a no-man's land of the electromagnetic spectrum for both research and development.



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Note: Foreign papers are to be su mitted in English. Technical Pr gram Committee should be a vised if any papers will have be presented elsewhere prior to t PGMTT Symposium.

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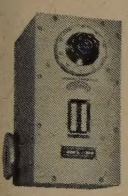

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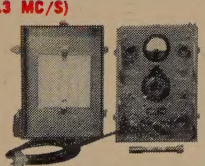

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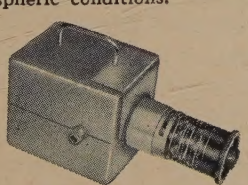

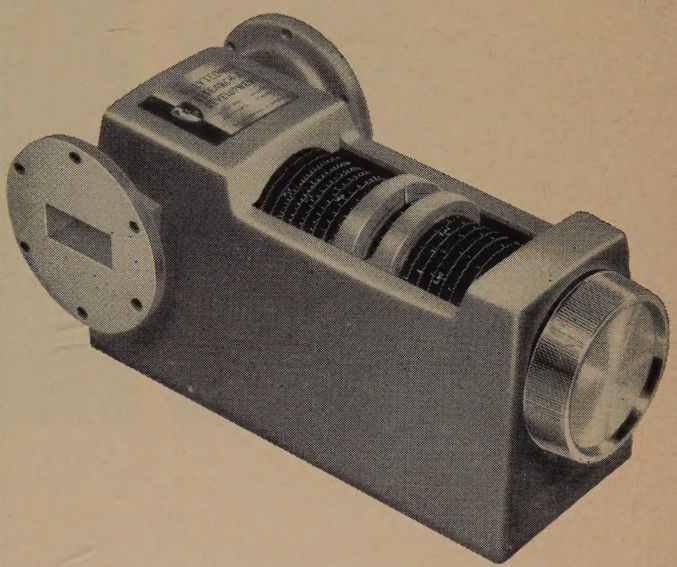

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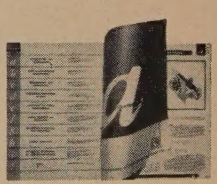

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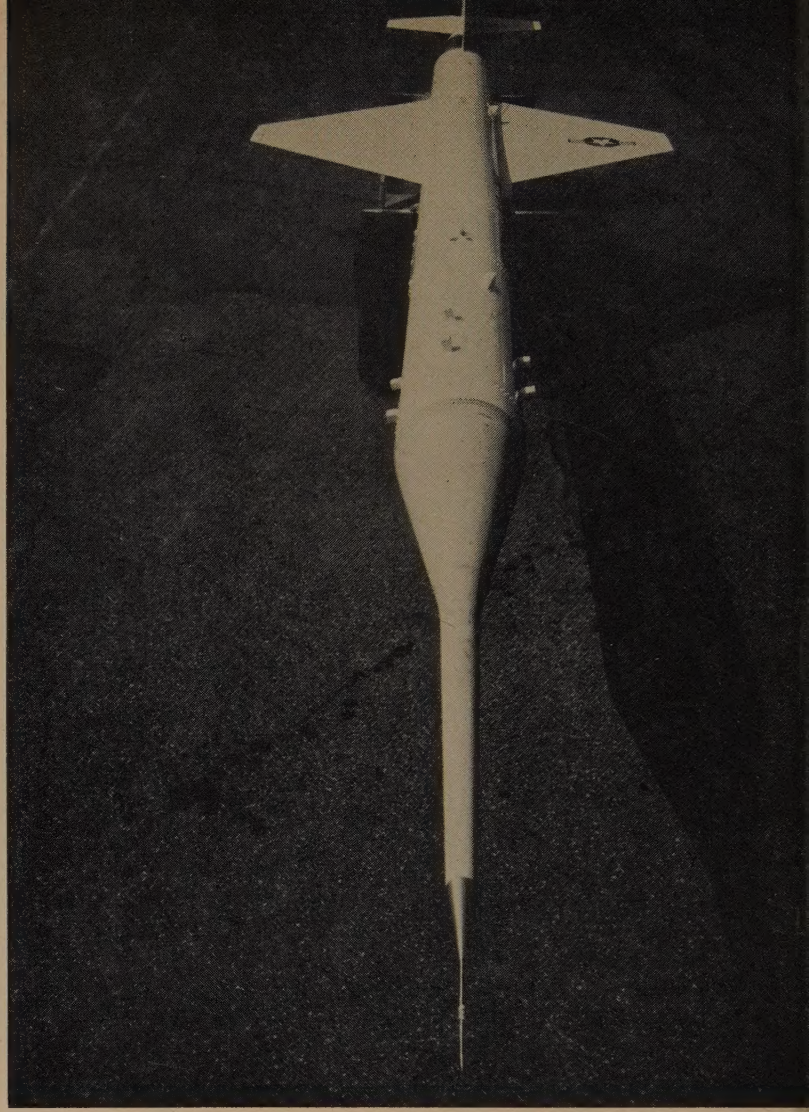

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Letters to the Editor

DITOR:

e microwave journal
oston, Mass.

In reading the November/Decem-er, 1958 issue of *the microwave urnal,* I noted and would like to cor-ct two errors that I made in the Maser" article. The first occurs in the ird column of Page 20 in which igure 13" and "80°" should read ig. 11" and "20°". The second error a more serious one in that it is mis-adir3, if not completely confusing. n Page 25 the noise temperature of 80 to 300°" should read "106° to 40°". Also in the same paragraph I as over enthusiastic in estimating timate noise figures of .2 to .8 db, this would not include antenna oise contributions.

In my article it was mentioned that e had achieved voltage-gain-band-idth products of the order of 100 Ic/s on masers developed in our lab-atory. Even though too late for in-rporation in that issue, I am pleased relate that simultaneously with the going to press" of that issue we hieved voltage-gain-bandwidth prod-cts in excess of 800 Mc/s. Because this break through, it can be ex-ected that the maser will play an im-ortant role in the field of radio tronomy.

WILLIAM H. FROM
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• • •

DITOR:

A copy of your journal has been rought to my notice by a Canadian esearch student who is at present orking in my laboratory.

I was very impressed by your in-iative in devoting a journal entirely microwave technique, and would ke to know if you extend your sys-m of complimentary copies to those ngaged in this field outside the U.S.A. nd Canada.

I am principally engaged in the aching of microwaves, and in re-arch on ferrites and microwave bes.

Yours faithfully,
J. ROBERTS
Imperial College of Science
and Technology
University of London

Starting with this issue, we are pleased to announce that the journal will be published on a monthly schedule. The response to date has been stimulating, but the real test lies ahead.

Of interest to the advertisers, in addition to the number of responses, will be the type of people responding. When originally conceived, it was felt that the magazine would be about microwaves and for microwave people. The overwhelming response of the first few issues has required us to modify this impression. If the answer cards are any criteria, the magazine will also be for people who are not necessarily microwave people as such, but who use microwaves in systems; e.g., electronic packages, communications, etc.

To get an accurate picture of our readership, we will send out questionnaires periodically. We beg your indulgence and request your cooperation.

One of the questions we hope to answer is how many people there are interested in microwaves from a purely commercial point of view. The main interest in the microwave industry, almost from its inception, has been for military applications. During the same period of time there has been a gradually increasing field of interest totally unrelated to the military. We hope our questionnaires and your response through the reader service cards will help to find some of the answers.

With the new monthly schedule we will need more material. We will be looking for more technical papers from our readers; also, more graphs, nomographs, and tables.

With the tremendous interest in the new field of solid state receivers, we are especially pleased to include a paper by Mr. Wesley G. Matthei. Mr. Matthei and Mr. Frank A. Brand in their work for the U.S. Signal Corps have been motivating forces in the evolution of the solid state receiver. Outside of a small circle of people working in the field of solid state, their contributions are practically unknown. For the people who do know of their efforts, it is generally conceded that the varactor and the resulting parametric amplifier might still be unheard of, had it not been for their foresight and diligence.

Our next issue will include Part II of Dr. Southworth's paper on the Smith Chart. In addition, the technical section will include "Systems Applications of Ferrite Circulators" by Tore Anderson, "Principles of Microwave Interactions with Ionized Media" by R. F. Whitmer, and "Temperature Compensation of Ferrite Isolators" by Wheeler and Rajock. The company profile will be about Airtron, a division of Litton Industries, the business editorial will be by Charles Creaser of the D. S. Kennedy Co. and a guest editorial by H. A. Finke of Polytechnic and Research Development Co.

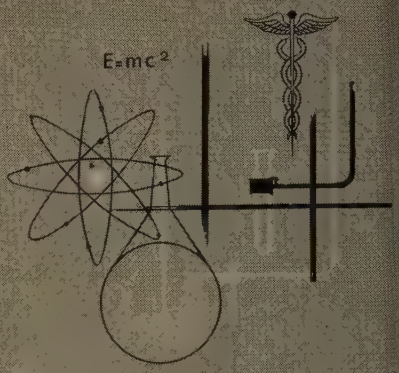
The interest in our next two issues will be centered on the IRE exhibit in New York. It is our intention to feature microwave activities at the show. We can now concentrate on those microwave firms who are exhibitors and will feature their new products, special booth attractions, and the personnel manning the booths. By having a source of information available, we hope you can use "the microwave journal" as a guide during your visit. By minimizing your wandering at the exhibit, we will be "SAVING YOUR TIME."

News of the National Symposium of the PGMTT, to be held in Cambridge at Harvard University on June 1-3, 1959, will be featured in subsequent issues. We will keep the microwave engineer alerted as this program unfolds.

Some of the countries from which requests have been received are: Canada, Scotland, England, France, Sweden, Italy, Jordan, Japan, and Brazil. The international scope of "the microwave journal" has impressed us, and we are pleased at this interest shown in "the microwave journal" outside the U.S.A.

Theodore S. Saad

140 KMC



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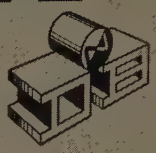

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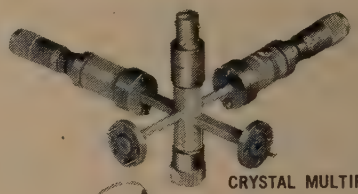
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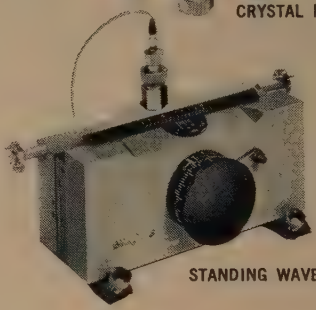
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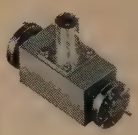
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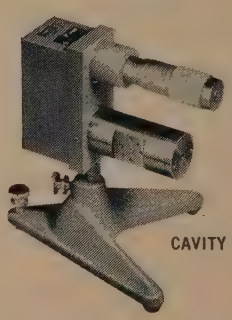
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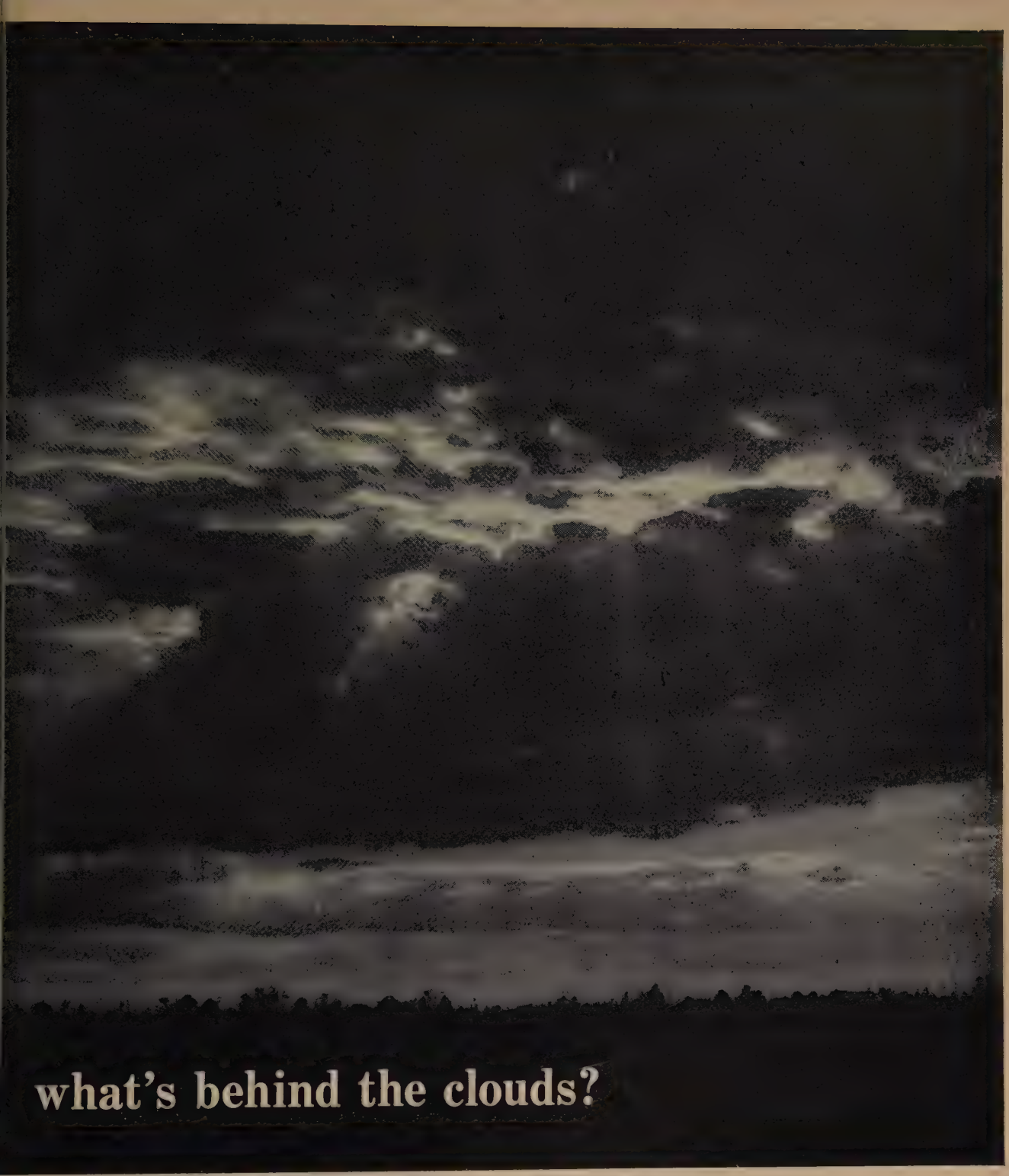

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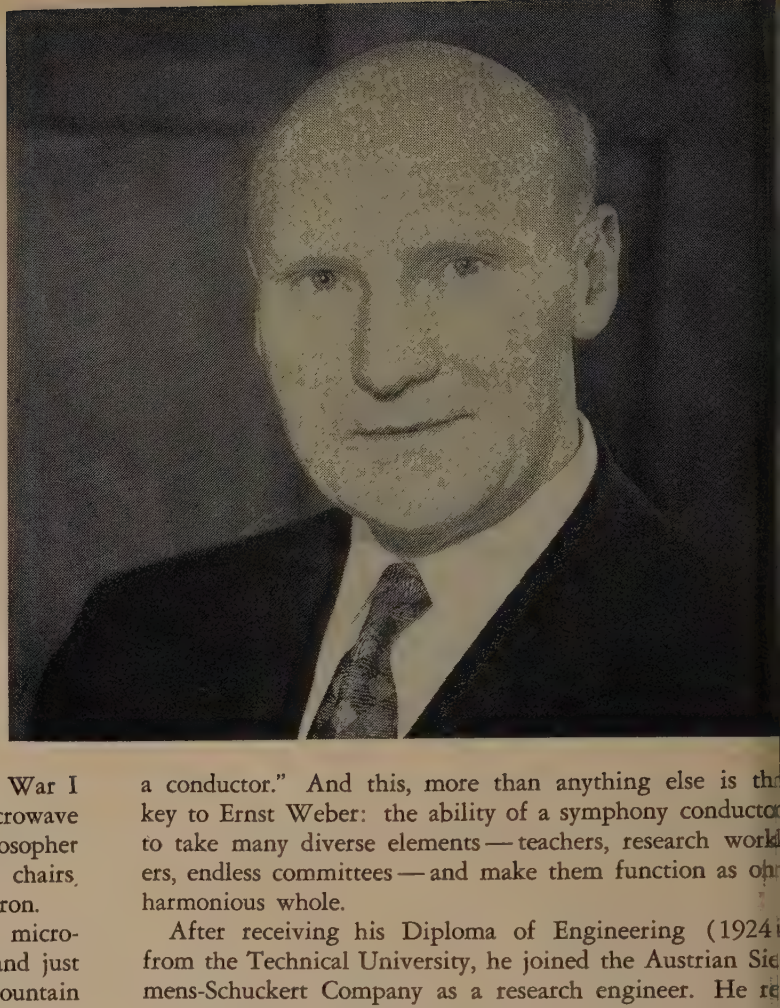
BIOGRAPHY

Dr. Ernst Weber

Pres. Polytechnic Institute of Brooklyn



IF THE MARKET for philosophers in post World War I Austria had been bullish, the world of the microwave might be poorer today. But then as now the philosopher went begging or scrambled for the few university chairs, and Ernst Weber turned his attention to the electron.

Thirty-two years later, however, this pioneer in microwaves retains his life-long interest in philosophy and just about anything else one could think of — from mountain climbing to French poetry, from higher education to ping-pong.

This ability to do many things almost simultaneously enables him today to be president of one of the largest technical universities in the country, president of a thriving electronics corporation, and president of the second largest professional society in the world — although he now admits that there is little time for ping-pong.

Dr. Weber was born in Vienna in 1901, the oldest of five children. Faced with the problem of continuing his secondary education in the depressed economy of a defeated nation, he turned his hand to tutoring some of his classmates in math and French: a feat he accomplished by keeping a few lessons ahead of them.

Generally you can speak of a man's college curriculum but in the case of Ernst Weber you must say curricula, for his interest in philosophy and engineering led him to pursue a dual course of studies; simultaneously attending the Technical University of Vienna and then tramping across town to attend the University of Vienna. Needless to say, his double life was unknown to the authorities at either institution.

Now that he is the president of a technical university he declines to say how he would react if one of his students followed the same course.

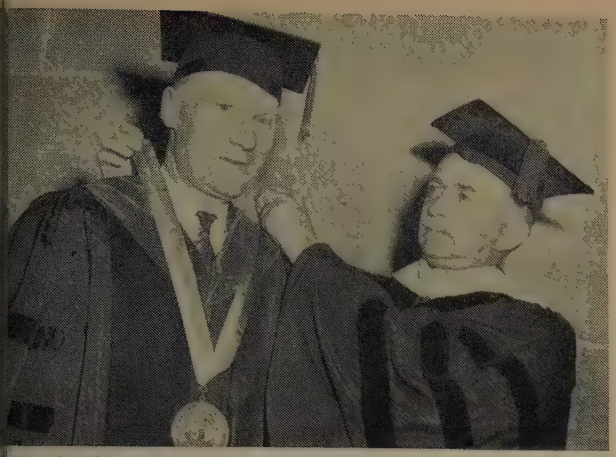
It was in his student days that his life-long love for music developed and, as he recounts it now, he walked miles to attend the concerts which were given in his native city. Today he is president of the Polytechnic Institute of Brooklyn and yet one of his deans says: "I think if Dr. Weber had it to do all over again, I'm certain he'd become a conductor." And this, more than anything else is th key to Ernst Weber: the ability of a symphony conducto to take many diverse elements — teachers, research worke ers, endless committees — and make them function as on harmonious whole.

After receiving his Diploma of Engineering (1924 from the Technical University, he joined the Austrian Sie mens-Schuckert Company as a research engineer. He re ceived his Ph.D. from the University of Vienna in 192 and the D.Sc. from the Technical University in 1927. I 1929 he transferred to the Siemens-Schuckert in Berlin It was there that he first proved his exceptional ability i the classroom, for while working with S-S he also receive an appointment as lecturer at the Technical University.

In 1930 he accepted an appointment as visiting professo of electrical engineering at the Polytechnic Institute o Brooklyn. A year later he became permanent research pro fessor of electrical engineering and in the succeeding yea he became head of the department. Under his direction enrollment in electrical engineering grew from 405 stu dents to 2200 students, representing a sizeable proportio of Polytechnic's graduate and undergraduate enrollment o 5700. On the graduate level the department grew from few evening courses into one of the largest graduate de partments in the country, enrolling 13.8 percent of th national total.

Unstinted praise for his ability as a teacher comes fro many of his former students who insist that he stimulate thought simply by being present. E. W. Herold, directo of RCA's Electronic Research Laboratory in Princeto who studied under Dr. Weber, says categorically that h "is the most outstanding teacher of graduate subjects i electrical engineering that I have ever met."

Early in World War II, Dr. Weber organized a grou of microwave experts at Brooklyn Poly who develope among other things, the precision microwave attenuato sorely needed for the more accurate calibration of rada With the aid of Dr. John W. E. Griemsmann and D Anthony B. Giordano, the group grew and expanded i



ston R. Bassett, Chairman of Poly's Board of Trustees, pre-
ts the presidential seal, symbol of his office, to Dr. Weber.

The Polytechnic Institute of Brooklyn which faces Brooklyn's new $200,000,000 Civic Center. Poly's Microwave Research Institute is housed in a six story building a block away from the Polytechnic.

d of interest until, as the Microwave Research Institute, became the largest research group at Polytechnic, ex-nding more than $1,000,000 each year on a broad spec-m of research for the military services. For his work in s venture Dr. Weber was awarded the Presidential Cer-cate of Merit.

In 1943 when the finished models of the microwave at-uators were shown at MIT's Radiation Laboratory it was cided that they were indispensable for high-grade radar ts sets. The Armed Forces wanted to secure large num-s in a short time, and yet, because of the difficulties in-ved in the mass production of something so delicate l precise, no commercial company wanted to undertake s highly specialized job.

To overcome this, Dr. Weber prevailed upon the author-s at Brooklyn Poly to supply capital and in a loft build-g in Brooklyn his group began to produce this test equip-nt. At the end of World War II confidence in the tech-al ability of this group was so strong that it was decided continue the operation as the Polytechnic Research and velopment Corporation, now a tax-paying corporation ned by the Polytechnic Institute of Brooklyn. Today, th Dr. Weber as president and chief scientific director, company employs 250 people and produces the most mplete line of microwave test equipment available.

Following World War II the research program at the lytechnic Institute of Brooklyn grew to the point where, th more than $2,500,000 expended annually on research ojects, the Institute ranked eighth among the universities the United States in annual expenditures for research. So large was this operation that the creation in 1957 of vice-president for research was called for. The choice of . Weber as v.p. was unanimous. Succeeding him as head MRI was a former student, Dr. Nathan Marcuvitz, while . John G. Truxal, who had come two years earlier from rdue, took charge of the electrical engineering depart-nt.

Hardly had Dr. Weber settled down as v.p. for research en Dr. Harry S. Rogers, president of the Institute, died ddenly. The Board of Trustees immediately named Dr. eber acting president on June 7, 1957 and the long rch for a new president began. Six months later, on cember 20, Preston R. Bassett, chairman of the board of stees, called a special meeting of the faculty and staff announced that after a six-month-long, nation-wide rch the board of trustees had decided that no better qualified president could be found than Dr. Weber.

True to past performance, Dr. Weber had been in office only six months when he announced a $15,000,000 expansion program to complete the interior construction in the Institute's new quarters, to erect a modern scientific library for 200,000 volumes, a student/alumni center and a graduate student dormitory. Again, within his first half year's tenure, Polytechnic scholarships were more than doubled.

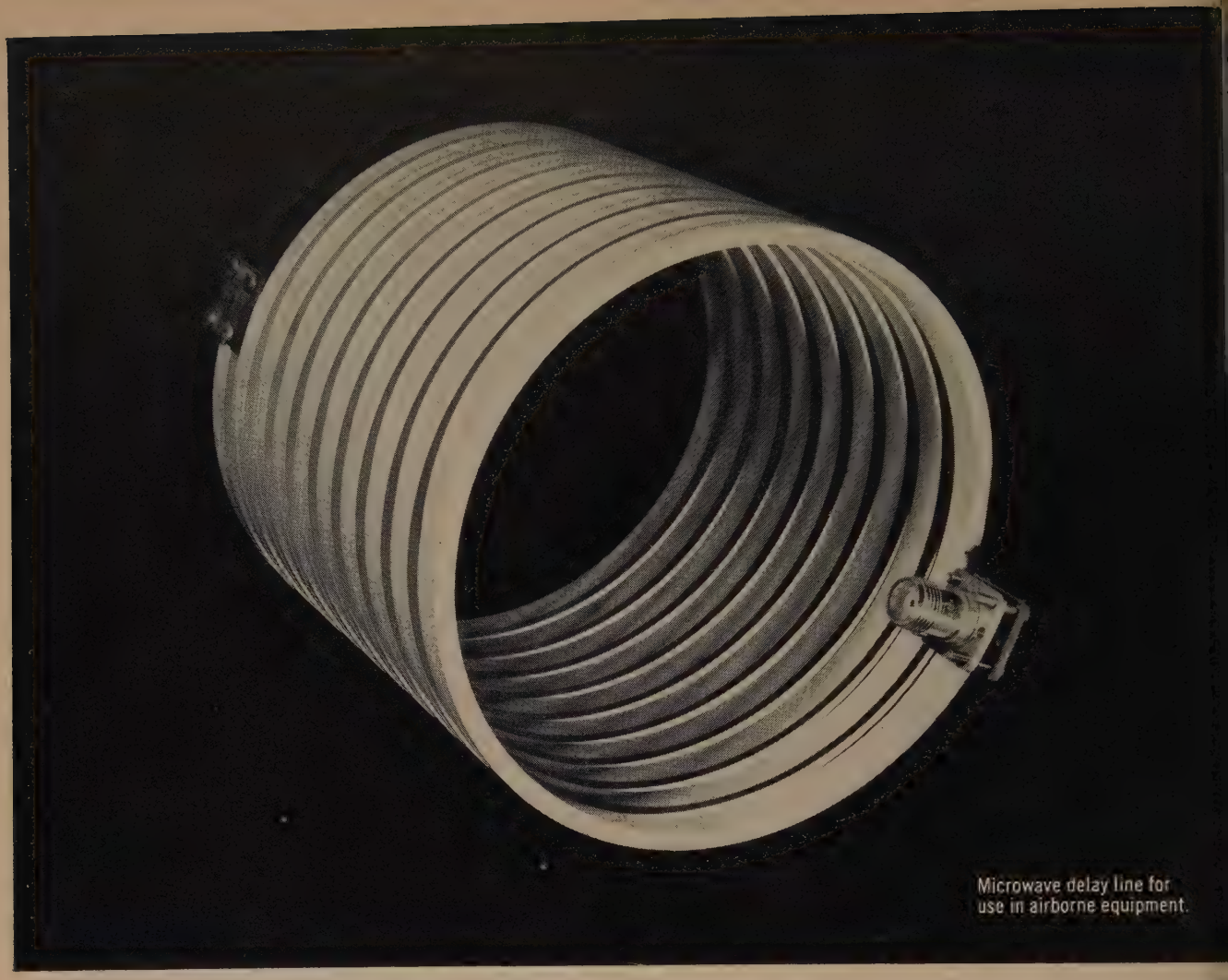
To cap his first year as president of Brooklyn Poly, Dr. Weber was elected president of the Institute of Radio Engineers and named a member of the Army's Scientific Advisory Committee.

In a busy life as an educator, a business man and a research worker, Dr. Weber has filed more than 50 American, Canadian and British patents in the field of microwave techniques. His published works include many papers on electromagnetic fields, linear and non-linear circuits, and microwave measurements. In addition to contributing to many texts, he is the author of *Mapping Fields* and *Linear Transient Analysis.*

A large Tudor house in Mount Vernon, where Dr. Weber lives with his wife, Dr. Sonya Weber, has become a familiar meeting place for the faculty and staff of the Polytechnic for he is a firm believer in the value of social intercourse as a means of improving professional competence. Over the years, many are the graduate students who have played ping-pong there with his two step-daughters or have enjoyed musicales by Mrs. Weber as Dr. Weber has sat quietly in a chair directing, with waving fingers, some unseen orchestra. At other times he enjoys quiet evenings in a well-stocked library with some of his favorite poets, such as Schiller, Heine, Verlaine or Rainer Maria Rilke whom he reads in the original.

Summer vacations are spent either in the Alps or the Rockies where Dr. and Mrs. Weber, herself a member of the faculty of the College of Physicians and Surgeons of Columbia University, share their unbounded enthusiasm for mountain climbing. Perhaps Dr. Weber's rapid, long-legged stride is a result of his life-long passion for climbing but it frequently has uncomfortable results for his associates as they try to keep pace with him.

Recently at a Polytechnic party in Dr. Weber's home an associate walked into the living room, breathless and puffing. "Your directions said the house was three minutes from the station. I've been walking uphill for fifteen."



Microwave delay line for use in airborne equipment.

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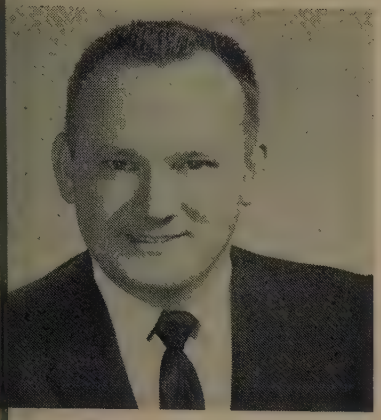

TWO MERGE INTO NEW COMPANY

eorge E. Hewitt formerly Execu- Vice President and General ager of the Canoga Corporation nnounced the formation of Ra- onics, Inc.

irectors of Radiatronics are Fred- L. Anderson, (Maj. Gen. USAF ; and Laurence G. Duerig of Alto; Donald Royce, Sr. of Los eles; and George Hewitt. In ad- n to the directors Edward H. r of Palo Alto is also a major holder.

vo Companies, Airad Co. and Manufacturing Co., have been ed into Radiatronics to provide pecialized manufacturing facili- equired for Microwave and An- a Systems work. These Com- es have been engaged in manu- ring this type of equipment for glas, Lockheed Missile Systems ion; North American, Northrup several other Southern Califor- irms during the past six years.

ck Webb and John Riley will inue to manage the Airad and Manufacturing Divisions of the firm. Mr. Hewitt whose early neering experience in this field ed at the Radiation Laboratory he Massachusetts Institute of nology is now forming a group xperienced Microwave, Antenna, Mechanical Engineers.

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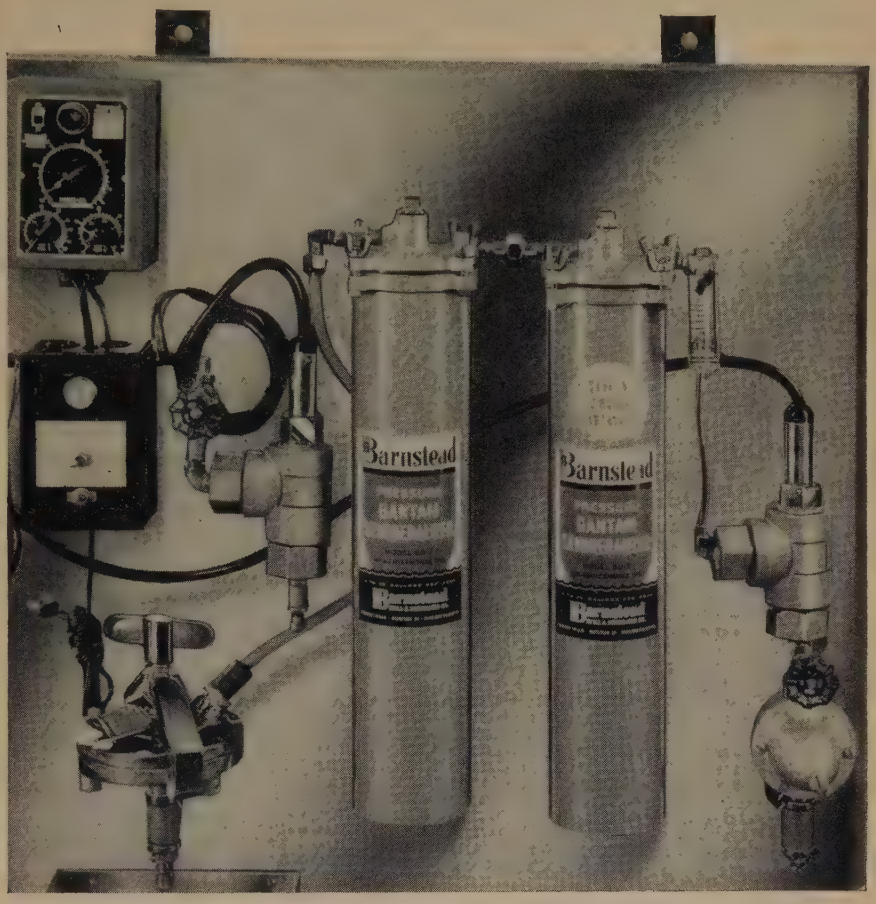

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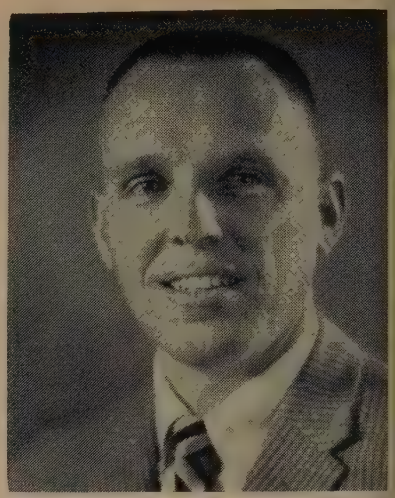


WESLEY G. MATTHEI (M56) was born in Jamaica, New York, on 11 September 1927. After a brief tour with the U. S. Navy in 1945-1946, he entered Hofstra College, Hempstead, New York in 1947. He then transferred in 1948 to the Polytechnic Institute of Brooklyn where he received the B.S. degree in Physics in 1950. Since that time he has continued graduate work at the Polytechnic Institute of Brooklyn. From 1950 to 1952 he served in the U. S. Army, where he worked on research problems in thermionics at Evans Signal Laboratory in Belmar, New Jersey. Since that time he has worked on various research and development problems in the field of solid-state devices. At present he is in charge of the Device Research Section of the Solid State Devices Branch, of the U. S. Army Signal Research and Development Laboratory.

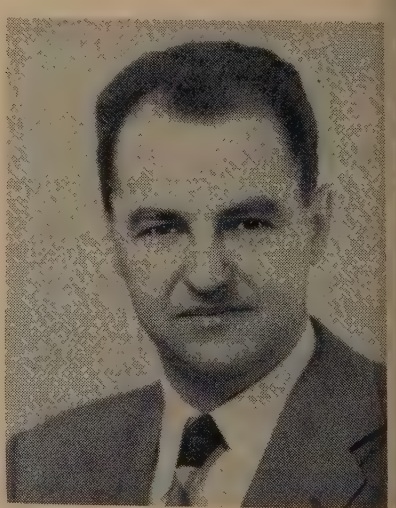
Mr. Matthei is a member of the American Physical Society and the American Association for the Advancement of Science.

CHARLES SÜSSKIND was born in Prague in 1921, and received his secondary education in Czechoslovakia and in Great Britain. He graduated from the California Institute of Technology in 1948, and received the M. Eng. and Ph.D. degrees from Yale University in 1949 and 1951, respectively. During World War II, Dr. Süsskind served with the U. S. 8th Air Force in Europe as an airborne-radar specialist.

His interest in the microwave field led to a doctoral thesis on artificial dielectrics. An article based on this dissertation, published by the British IRE, earned him the Clerk-Maxwell Premium for "the most outstanding paper published in the Institution's Journal" in 1952.

Between 1951 and 1955, Dr. Süsskind was a research associate at Stanford University, at the same time serving as Lecturer in Electrical Engineering and (after 1953) as Assistant to the Director of the Microwave Laboratory. "In 1955, he was appointed to the faculty of electrical engineering at the University of California, where he is now Associate Professor."

Dr. Süsskind is a senior member of the IRE; a member of the American Physical Society, the American Society for Engineering Education, The History of Science Society Tau Beta Pi and Sigma Xi; and an associate member of the British IRE. In addition to his scientific and technical contributions (especially in the field of electron tubes), he has published many articles on the topic of engineering education.



Dick Barlow was born in Earlsboro, Oklahoma. He obtained both a BSEE and a BS in Education, with honor, from Oklahoma Institute of Technology. In 1936, he was an instructor of electrical engineering at the University of New Mexico. At Bell Laboratories from 1937 to 1950, his work included design of television transmission systems, radars and computers for anti-aircraft, bombing and airborne fire-control systems, microwave television repeaters, and electronic switching. His work at Bell Labs was interrupted in 1942 for a tour of duty with the Signal Corps. At Hughes Aircraft Company since 1951, he now has the position of Manager, Electron-Tube — Industrial Systems Division of Hughes Products. Dick is a senior member of I.R.E., Research Society of America, Aircraft Electrical Society, Kappa Delta Pi and Eta Kappa Nu. His wife and three children share his interests in camping and mountain climbing.

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Tuning Range	5400-5950 MCS	5400-5950 MCS	5400-5750 MCS
3 db Bandwidth	8-11 MCS	8-10 MCS	8-9 MCS
Max 30 db Bandwidth	60 MCS	32 MCS	21 MCS
Max Insertion Loss	2 db	3 db	4 db
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Type of Resonant Cavity	λ/4 coax	λ/4 coax	λ/4 coax
Tuning Range	960-1150 MCS	960-1100MCS	960-1050 MCS
3 db Bandwidth	8-11 MCS	8-10 MCS	8-9 MCS
Max 30 db Bandwidth	60 MCS	32 MCS	21 MCS
Max Insertion Loss	1.2 db	1.8 db	2.5 db
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Tuning Range	7500-8500 MCS	7500-8250 MCS	7500-8000 MCS
3 db Bandwidth	8-11 MCS	8-10 MCS	8-9 MCS
Max 30 db Bandwidth	60 MCS	32 MCS	21 MCS
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Price	$475.00	$625.00	$775.00
Model No.	85-BW	85-CW	85-DW
Type of Resonant Cavity	TE_{111} mode cylindrical	TE_{111} mode cylindrical	TE_{111} mode cylindrical
Tuning Range	8500-9600 MCS	8500-9300 MCS	8500-9000 MCS
3 db Bandwidth	8-11 MCS	8-10 MCS	8-9 MCS
Max 30 db Bandwidth	60 MCS	32 MCS	21 MCS
Max Insertion Loss	1.5 db	2.5 db	3.5 db
Price	$475.00	$625.00	$775.00

All of the above filters have Max VSWR of 1.5, and either a single shaft or counter dial for Tuning Control. Depending upon mode of operation, units are supplied with either Type N Connectors or Waveguide flanges.

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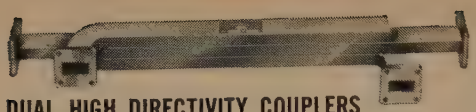


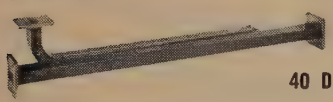
DUAL HIGH DIRECTIVITY COUPLERS

Narda Dual High Directivity Directional Couplers are designed for reflectometer measurements in waveguide systems, and exhibit the same flat response (± 0.4) and high directivity (40 db min.) as Narda's single units. Primary line VSWR: 1.05 max. (1.10 for M1027); secondary line VSWR: 1.15 max.

Coupling structures are on opposite broad walls of the primary line; secondary output arms are on the same side. Detector mounts can be attached readily to facilitate connecting detector mounts.

BAND	FREQUENCY (kmc)	WAVEGUIDE O.D. (in.)	NARDA Model	PRICE
S	2.60-3.95	3 x 1½	1034	$650.
C	3.95-5.85	2⅛ 1	1033	400.
XN	5.40-8.20	1⅝ x ¾	1032	255.
XB	7.05-10.0	1¼ x ⅝	1031	220.
X	8.20-12.4	1 x ½	1030	175.
KU	12.4-18.0	.702 x .391	1029	180.
K	18.0-26.5	½ x ¼	1028	295.
V	26.5-40.0	.360 x .220	V1027	330.
M	50.0-75.0	.228 x .154	M1027	900.

3, 6, 10 and 20 DB



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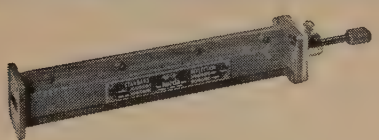
The 40 db High Power Coupler is another exclusive Narda product. Similar to standard types, except that coupling irises are in the narrow wall, it may be used at full rated power of the waveguide size. Nominal coupling value is 40 db; directivity 40 db. Directivity for 3, 6, 10 and 20 db couplers is also 40 db. Standard cover flanges on primary line; low VSWR termination and standard cover flange on secondary. All bands—2600 to 90,000 mc.



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Reflection Coefficient	0.00	0.05	0.10	0.15	0.20
Accuracy	0.002	0.0025	0.0035	0.0045	0.007
VSWR Equivalent	1.00	1.105	1.222	1.353	1.50

Models for 2.60 to 18.0 kmc, from $125 to $300

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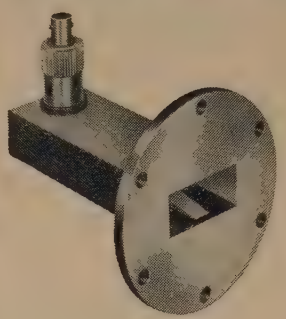

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This new series of Narda matched Bolometer-Thermistor Mounts offers the optimum in accuracy and flexibility. At the same time, they permit instant replacement of the element. Bolometers and Thermistors, available from stock, simply plug in, without the use of tools, without the need of adjustments.

In addition, these mounts offer an extremely low VSWR over the full waveguide band, and require no tuning. Using bolometers, these units are designed for highest accuracy square law detection and power measurements. The thermistors are particularly recommended for accurate pulse power measurement. The new Narda N-605 Bolometer and N-333D Thermistor are recommended for use in these new detectors.

BAND	FREQ (KMC.)	WAVE GUIDE (IN.)	NARDA MODEL	DETECTOR TYPE AND MODEL	MAX. VSWR	CRYSTALS†	LENGTH (IN.)	PRICE
L	1.12-1.70	6.66x3.41	536	BOLOMETER N-605 THERMISTOR N-333D	1.35 1.5	IN21 or IN23	14	$210.
LS	1.70-2.60	4.46x2.31	535	BOLOMETER N-605 THERM STOR N-333D	1.35 1.5	IN21 or IN23	9	210.
S	2.60-3.95	3x1½	534	BOLOMETER N-605 THERMISTOR N-333D	1.35 1.5	IN21 or IN23	7¼	110.
C	3.95-5.85	2x1	533	BOLOMETER N-605 THERMISTOR N-333D	1.5 1.5	IN21 or IN23	5⅜	80.
XN	5.40-8.20	1½x¾	532	BOLOMETER N-605	1.5	IN23	4⅛	90.
			542	THERMISTOR N-333D	1.5	IN23	4⅛	75.
XB	7.05-10.0	1¼x⅝	531	BOLOMETER N-605	1.5	IN23	3¼	85.
			541	THERMISTOR N-333D	1.5	IN23	3¼	65.
X	8.20-12.4	1x½	530	BOLOMETER N-604	1.5		2⅛	65.
			540	THERMISTOR N-336	1.5		2⅛	60.
KU	12.4-18.0	.702x.391	529	BOLOMETER N-604	1.5		2	65.
			539	THERMISTOR N-336	1.75		2¼	95.
K	18.0-26.5	½ x ¼	538	BUILT-IN THERMISTOR	2.0		1¾	150.

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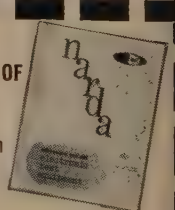

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RECENT ADVANCES IN SOLID STATE RECEIVERS

by

WESLEY G. MATTHEI

U.S. ARMY SIGNAL RESEARCH AND DEVELOPMENT LABORATORY
FORT MONMOUTH, NEW JERSEY

INTRODUCTION

ecent scientific discoveries in the l state field have led to engineer- advances in the low-noise re- er field. New devices, through opriate modifications, have been loped from such widely diverse s as the quantum mechanical as- s of energy levels and electron s, to the classical concepts of ed oscillations. For example; the l state maser,[1] the ferrite ampli- [2] and the varactor diode ampli- promise to revolutionize our ty to receive information effi- tly and reliably in the form of tromagnetic radiation.

With the advent of the fabrication ew variable capacitance semicon- or diodes[4], and the discovery ferrites can be used in at least e[5] or four[6] ways to build an lifier and, finally, the realization improved maser materials and niques,[7] broad-band and narrow- l receivers have been built up to and frequencies with effective in- noise temperatures of less than °K.

is the intent of this paper to ent a review of some of these nt solid state developments, and discuss the present and possible re characteristics of mavar and er[8] receivers. Other solid state elopments, such as a new trans- rized VHF receiver,[9] new micro- e crystal rectifiers,[10] harmonic llators,[11] or new diode protective ices,[12] etc., will not be covered his paper.

efore going into the presenta- of the results of the various es of amplifiers (receivers) that e been built recently, a brief gen- discussion on the application of se new devices to receiver systems robably in order.

The superheterodyne and crystal eo receivers, and the radiometer eiver would be capable of giving ter performance if a low-noise, h-gain, r-f preamplifier or ampli- were available for incorporation the system. These new solid e devices have been used as ight amplifiers, and also as fre- ncy converters in order to give improved system noise figure. example, Figure 1(a) shows, in ck diagram form, a superhetero- e receiver. The noise figure of receiver is given by the usual

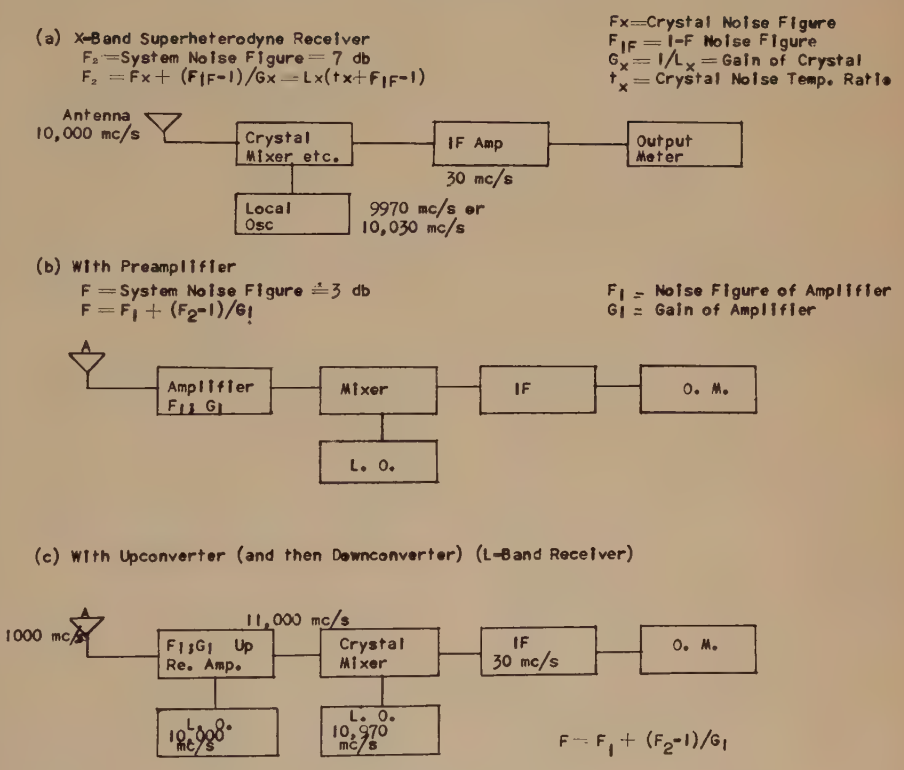


Figure 1

formula and, for purposes of illustration, is taken to be 7 db. Figure 1(b) shows, in block diagram form, a superheterodyne receiver with an r-f pre-amplifier "in front" of it. Figure 1(c) shows, in block diagram form, a receiver which first uses an upconverter stage, and then the usual down-converter superheterodyne stage. In both of these cases, the receiver noise figure is small (for purposes of illustration, 3 db) because, in each case, the first stage in the receiver has high gain with an associated low noise figure. Using these two techniques, mavars and masers have been used to obtain lower system noise figures. Some of

THREE LEVEL CAVITY SOLID STATE MASER WORK

Made by:	R. H. Kingston (Lincoln Lab) Proc. IRE Vol. 46 No. 5 p. 916, May 58	S. H. Autler & N. McAvoy (Lincoln Lab) Phys. Rev. Vol. 110, No. 1 p. 250-1 1 Apr 58	A. L. McWhorter & J. W. Meyer (Lincoln Lab) Phys. Rev. Vol. 109, No. 2, 15 Jan 58, p. 312-318.	L. E. Alsop, J. A. Geordmaine, C. H. Townes (Columbia U)
Material:	½% $K_3Cr(CN)_6$ in $K_3Co(CN)_6$	½% $K_3CR(CN)_6$ in $K_3Co(CN)_6$	½% Potassium (chromicyanide) in potassium (cobalti cyanide). ½% $K_3CR(CN)_6$ + 99½% $K_3Co(CN)_6$	Ruby + 0.1% Cr+++ impurities
Amplifier:				
Signal Freq.	300 Mc/s	1382 Mc/s	2800 Mc/s	9,100 Mc/s
Pump Freq.	5300 Mc/s	9070 Mc/s	9400 Mc/s	20,800 Mc/s
Pump Power	10 mw	28 mw	1 mw; 30 mw	5 mw
Power Gain	10 db	2.7 db: 5.7 db	37 db; 10 db	20 db
Bandwidth	100 Kc/s	1 Mc/s; 50 Kc/s	25 Kc/s; 500 Kc/s	10 Mc/s
Volt gain BW prod.		1.85×10^6 sec^{-1}	1.8×10^6 sec^{-1}	100 Mc/s; 50 Mc/s
Noise Fig; System	2 db (170°K)		20 + 50°K (F = 0.3 db) 2°K	F = 0.8 db 60°K
Noise Fig; Maser				F = 0.2 db 10°K
OSCILLATOR:				Noticed
Freq.			2800 Mc/s	
Input power			1 mw	
Output power	0.1 μw		—28.5 db	
Efficiency			0.14%	
OTHER CONDITIONS:				
DC mag. field	60 oersteds	1200 gauss	1.25°K	3700 gauss
Temp. Bath	1.6°K	1.25°K	Doubly resonant cavity	Liquid helium
	Tunable cavity arrangement	Double tuned cavity		Weight = 150 lbs
	Noise figure (second stage receiver) 4.9 db (600°K)			2 separate replaceable cavities

Figure 2

the published results are pointed out in the following sections, along with their advantages and disadvantages, if any.

DISCUSSION

The Maser

The maser is a quantum-mechanical amplifier that, in its operation, relies on the forced inversion of the population of electrons in at least two energy levels, and the levels' subsequent emission of radiation by the stimulation of an appropriate electromagnetic radiation, usually at microwave frequencies. The three-level solid state maser was first proposed by Bloembergen[13] and the first successful operation was reported by Scovil, Feher, and Seidel[14]. Since that time, other materials, techniques, and structures have been used with rather startling results. The data shown in Figure 2 is a presentation of the successful results of some of the experiments performed by many workers in this field. It should be noted that this data is not intended to be comprehensive in its coverage of all the maser work in progress, but that it merely tries to adequately cover the various and many aspects of maser amplifiers. Four masers which operate in four frequency bands are presented: UHF, L-band, S-band, and X-band.

Characteristic of these four doubly resonant, cavity-type, three-level masers are the high gains, narrow bandwidths, and low-noise figures obtained using an applied d-c magnetic field with an associated liquid helium temperature bath. The L-band maser could be used in radio astronomy since it is at the frequency of the 21-centimeter interstellar hydrogen line. The X-band maser has already been used in conjunction with the Naval Research Laboratory's radiometer.

These cavity types of masers, because they are inherently a reciprocal device, usually require isolation from the receiver and the antenna. This isolation is most conveniently obtained by the use of a circulator. Figure 3 shows the circulator-maser radiometer system used at NRL. Note that the maser operates as a one-port device.

About the time of the first successful operation of a cavity maser, it was recognized that slow-wave masers should be superior in performance to cavity masers. A slow-wave structure maser should, in principle, permit broad-band amplification and fast tunability, and should alleviate the problems connected with non-reciprocity and gain stability. Various groups in the country have been considering various slow-wave structures such as coupled double-tuned stripline resonators, a stripline modification called the "slanted-slab" structure, the interdigital and digital structures, and the helix. Figure 4 presents some data on the slow-wave digital structure constructed at BTL. The data presented describes the use of two five-inch pieces of chromium-doped ruby as the material. This C-band slow-wave maser has a bandwidth of 25 mc/s with a forward power gain of 23 db. Note that this maser is non-reciprocal, and that C-band frequencies are attenuated 29 db in the direction of the antenna. This maser, by electronically tuning the pump frequency and the magnetic field, has an electronically tunable range of 350 mc/s. In addition, when stagger-tuned, a forward gain of 13 db was obtained with a bandwidth of 67 mc/s. At the bottom of Figure 4, a slow-wave maser is schematically shown in a system as a two-port unidirectional device which makes the use of a circulator unnecessary. Additional work has been reported using gadolinium ethyl sulfate.[15]

The significance of the slow-wave maser structures is that broad-band, high-gain, and very low-noise figure amplifiers should become available in the near future. At the present time

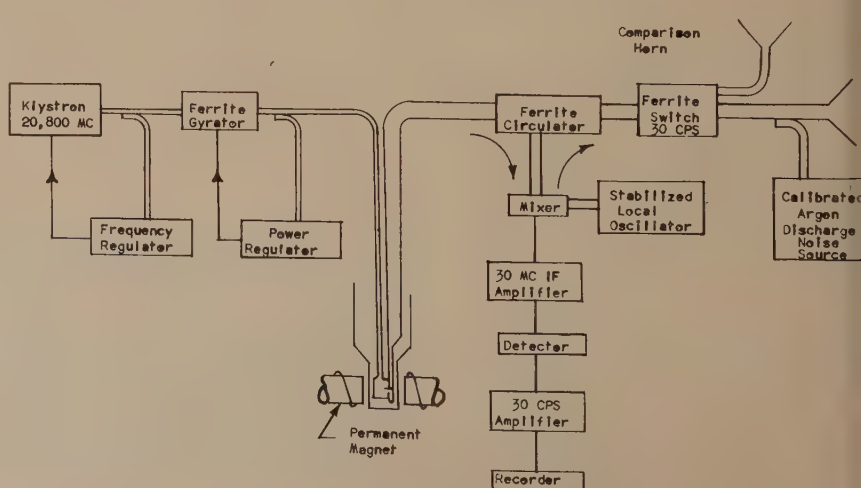


Figure 3

nasers require the application of d-c nagnetic fields, and the environment f a liquid helium temperature bath vhich could be a detriment in some pplications. In addition, the maser aturates (becomes inoperative) for n appreciable period of a second vhen signal levels greater than a cer-ain threshold power are applied. This long recovery time, wherein the mplifier is not operating, may pre-ent the maser from being used in ome applications, such as a radar ystem unless an efficient switch is sed.

Materials research coupled with tructure research may lead to the se of masers in many types of appli-ations. In the future, optical pump-ng with a "yet to be discovered" naser material may allow room-tem-erature operation. However, it hould be emphasized that realiza-ion of this kind of speculation de-ends on a vigorous research and de-elopment effort in this area.

TYPE: Three-Level Slow-Wave Structure Maser — R. W. DeGrasse, E. O. Shulz-DuBois, R. E. D. Scovil and H. Seidel (BTL)

MATERIAL: Ruby (Al_2O_3) + 0.05% Cr^{+++}

AMPLIFIER:
Signal Frequency: 5900 mc/s
Pump Frequency: 18,900 - 19,500 mc/s
Pump Power: 100 mw
Forward Power Gain: 23 db Bandwidth: 25 mc/s
Reverse Loss: 29 db
Electronically Tunable Ranges: 350 mc/s
Output Power (CW): - 22 d bm
Output Power (Pulse): +8 d bm (30 db duty factor)
Noise Figure:

OTHER CONDITIONS:
Magnetic Field: 3700 gauss
Digital Slow Wave Structure
Recovery Time: 0.2 sec
Structure Length: 5 inches
Liquid Helium Temperature
Stagger Tuned: Forward Gain 13 db; Bandwidth: 67 mc/s

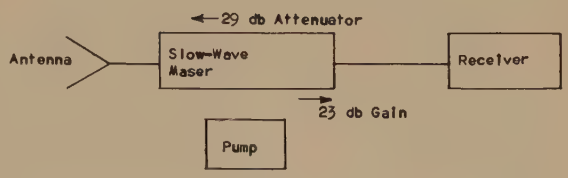


Figure 4

The Ferrite Amplifier

The ferrite amplifier may be described as a parametric amplifier which uses a non-linear magnetization effect as the variable reactance. Suhl[16] has proposed that one can use the magnetostatic modes of the ferrites to build an amplifier in one of three different ways. Like the maser work, the first types of ferrite amplifiers were constructed using a cavity-type structure. Slow-wave structures are undoubtedly being considered by many, including P. K. Tien and H. Suhl.[17] Because of the relative newness and complexity of this field, only two ferrite amplifiers have as yet been announced. The first ferrite amplifier was built by M. T. Weiss[18] of BTL. He used the "electromagnetic" mode of operation in the degenerate parametric amplifier case, the signal and the idler frequency being identical. Figure 5 presents the results of his work. The significance of the operation of this ferrite amplifier (besides the important fact that it gives gain) is that 100 watts peak power output was obtained at room temperature operation. At the present time, there is no reason to suspect that anything but a low noise figure should be possible.

In addition to Weiss' work, which was based on one type of Suhl's proposed amplifiers, A. D. Burk, L. Kleinman, and C. E. Nelson[19] have recently announced the successful operation of a modified version of the previously proposed semistatic type of operation. A summary of their results is shown in Figure 5. The startling results of this work are the high gains that have been obtained, i.e., 60-100 db. It is interesting to note that with gains as large as these, the noise of the pump which is introduced into the amplifier is no longer insignificant, but may be a major contribution to the noise figure.

Again, a slow-wave structure should lend itself to higher operating bandwidths with associated high gains and low noise figures. P. K. Tien and H. Suhl[20] have recently published a paper on the theory of a ferromagnetic travelling-wave amplifier of the parametric type. Figure 5 presents some of these theoretical calculations on such a device. It should be noted that the gain of this type of device depends on the length of the structure; the longer the structure, the higher the gain.

Using a travelling-wave structure, Tien and Suhl postulate bandwidths from a very low frequency up to the energizing frequency. However, like the maser field, much research and development work must be done on

FERRITE AMPLIFIERS

Made by:	M. T. Weiss (BTL) Phys Rev. Vol. 107, p. 317 — July 57	A. D. Burk, L. Kleinman, C. E. Nelson (Hughes) Presented at WESCON — 20 August 58	P. K. Tien & H. Suhl (BTL) Proc. IRE Vol. 46 No. 4, p. 705-6 April 58
Material:	Single crystal of manganese ferrite (resonance line width ≅ 40 oersteds)	TRANSTEX 414 Ferrite (line width = 100 oersteds)	Yttrium iron garnet — line width = 3 oersteds
Amplifier:			
Signal Frequency	4500 Mc/s	6000 Mc/s	6.5 Kmc/s
Pump Frequency	9000 Mc/s	9000 Mc/s	9 Kmc/s
Pump Power	(magnetron) 20 kw peak (3 sec duration)	1 Kw	3,375 x (volume — cm^3) watts
Power Gain	8 db	60-100 db	Power gain/unit distance = 0.551 db/cm
Bandwidth		2 Mc/s	
Noise Figure	Not measured		not measured or calculated
Power Output		up to 5 watts average 100 watts peak	
Oscillator:		None noticed	
Power Output	100 watts peak power		
Pump Power (magnetron)	30 —kw peak power		
Other Conditions:			
DC magnetic field		700-800 oersteds	3750 oersted
Type structure	doubly tune cavity	doubly resonant cavity	Slow wave — parallel wire structure
Ambient Temperature	Room temperature ambient	Room temperature ambient	Room temperature ambient

Figure 5

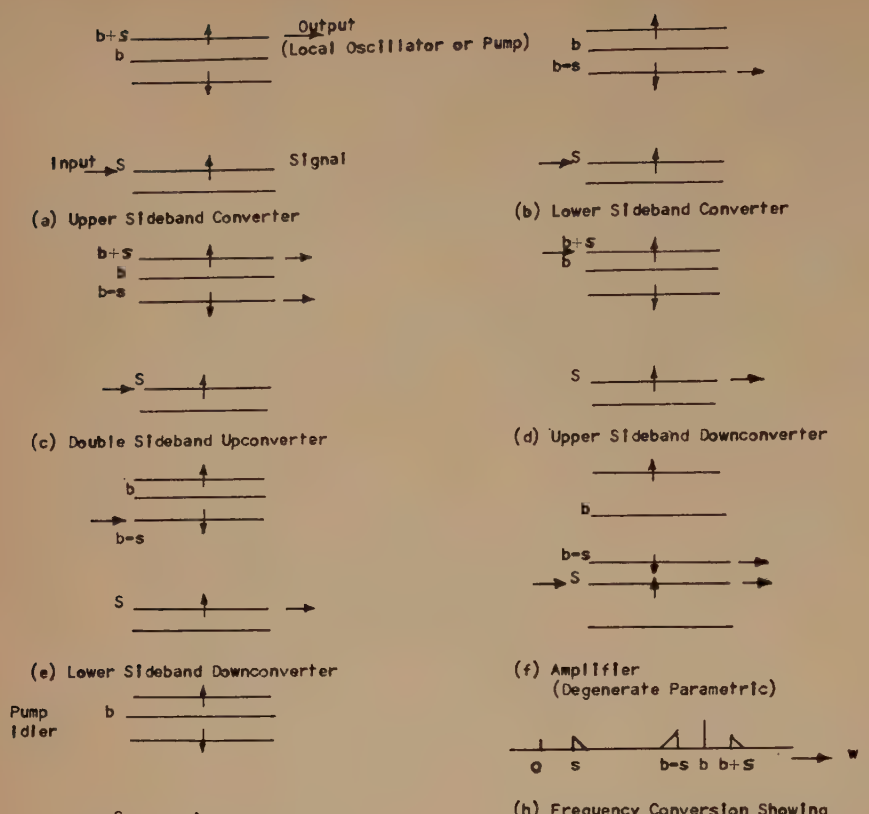


Figure 6

the materials and structures in order to permit these predictions to become a reality.

Varactor Diode Amplifiers

A varactor diode amplifier depends on a semiconductor diode for its non-linear capacitance circuit parameter. The diode acts like a parallel plate condenser; the distance between the plates being varied in a non-linear way by the application of a varying voltage.

Not only have varactor diodes been used in the parametric mode of amplification, but they have also been used in other converter combinations such as the upconverter plus downconverter mode of amplification, or the upper-sideband amplifier, etc.

It has been shown that almost all types of varactor diode frequency converters can give power gains with an associated low noise figure. In his recent paper, A. Uhlir [21] pointed out various types of frequency converters or amplifiers. Figure 6 presents the various frequency relations that are involved. It should be noted that the lower sideband has an inverted spectrum; that is, if the signal frequency (spectrum) increases, the lower sideband signal (spectrum) decreases.

It has been shown by Manley and Rowe [22, 23] that the upper-sideband converter, Figure 6, case a, can give a power gain equal to the ratio of the upper-sideband frequency to the signal frequency. Case b, the lower-sideband converter can give unlimited power gains since the diode can operate in a potentially unstable condition due to the negative resistance effect which is characteristic of this type of operation. Hines [24] has pointed out that for the double-sideband converters, case c, unlimited power gain can be obtained at both sidebands. An upper-sideband down-converter, case d, as Uhlir [25] has shown, will produce a stable power loss using a non-linear capacitor; therefore, non-linear resistors (microwave crystal rectifiers) are preferable. The lower-sideband down-converter, case e, can give unlimited gain, but operation in this case is also potentially unstable. Case f is the degenerate parametric amplifier in which the signal and the lower-sideband are either identical or approximately the same values. Case g represents the classical parametric amplifier in which a signal is amplified by the use of an idler circuit which allows the "pump" power to be coupled into the signal circuit at the signal frequency.

There have been many diode amplifiers constructed using these seven frequency relationships. Experimental results are presented in Figure 7 on four of the first five of these frequency relationships; that is, the various kinds of frequency converters.

The upper-sideband upconverter case, shown in Figure 7, column 1, illustrates the fact that high power

Semiconductor Reactance Diode Frequency Converters

	1	2	3	4
Made by:	G. Sard, J. Green, B. Salzberg & P. Lombardo A.I.L.	M. E. Hines: Paper presented at 15th Annual Conference Electron Tube Research, Berkeley Calif., June 1957	G. F. Herman, M. Uenohara, A. Uhlir Proc. I.R.E. Vol. 45, p. 1301-2 June 58 (BTL)	A. Uhlir, BTL Chapter 3 — "Improved Crystal Rectifiers" 1st Interim Rpt; DA 36-039 sc-73224
Type Diodes:	(M-2102) Diffused junction silicon varactor	Silicon point contact microwave crystal rectifier (experimental)	M-2102 & WE427A	M-2102
Type of Freq. Converter	Upper Sideband up converter	Lower Sideband up converter	Double Sideband up converter	Lower Sideband down converter
Signal Freq.	400 Mc/s	6165 Mc/s	460 Mc/s	460 Mc/s
Pump Freq.	8900 Mc/s	12,350 Mc/s	8915 Mc/s	520 Mc/s
Converted Freq.	9300 Mc/s	6,185 Mc/s	9375 Mc/s	60 Mc/s
Pump Power	100 mw	1 mw	200 mw	
Power gain	11 db	gain noticed	21 db	45 db
Bandwidth	25 Mc/s	not measured	not measured	0.17 Mc/s
Noise Fig (System)	1.9 db 160°K	not measured	1.1 + 0.5 db (87 + 40°K)	high
Noise Fig (converter)	0.57 db 40°K	not measured	not given	not measured
Oscillator:	Theoretically impossible (Not observed)	Noticed when pump power = 1 mw freq of oscillator=6175 Mc/s ½ volt reverse bias on diode	No data	Noticed
Other Conditions: Operating Temp.	Balanced mixer input Room temperature	Reverse bias on diode = 1 Volt Room temperature	Second stage noise figure = 7 db	diode freq. cutoff 40 Kmc/s

Figure 7

ains and wide bandwidths can be
eadily obtained for this potentially
able case of frequency conversion.
is also very significant that very
w system and converter noise fig-
es were measured. Of interest also
the fact that a balanced mixer in-
ut was utilized in order to reduce
e signal noise sideband power.
The lower-sideband upconverter
se, shown in column II of Figure
is significant in that not only was
the first experiment which con-
med the theory, but also that gains
d oscillations were noticed by util-
ing an experimental silicon point
ntact microwave crystal rectifier.
olumn III of Figure 7 presents
ata on the double-sideband upcon-
erter case. It should be noted that
e observed gain is greater than the
tio of the frequencies (9375/460
= 13 db) which is characteristic of
uble-sideband frequency upcon-
erters. A very low receiver noise
gure was measured also.
The upper-sideband downconverter
se is not shown in this Figure be-
use no data using varactor diodes
e available. For this case one would
xpect that, if a varactor diode were
sed, a stable power loss of the
rder of the ratio of the signal (i-f)
requency divided by the upper-side-
and frequency (s/b+s). Non-linear
esistors (1N23WE and 1N21WE
icrowave crystal rectifiers) are,
herefore, preferred in this type of
rcuit.
Column IV of Figure 7, however,
resents data on the potentially un-
able lower-sideband downconverter
se. Characteristic of this type of
peration is the high gain and very
arrow bandwidths which can be ob-
ined. This case, like the preced-
ng one, corresponds to the usual
perheterodyne type of receiver.
The other two cases are presented
Figure 8. In column I of Figure
, data on the parametric type of
mplifier are presented. It should be
oted that the sum of the signal and
dler frequencies adds up to the
ump frequency. In addition to ob-
ining power gains of over 40 db,
scillations were observed at both
e signal and the idler frequencies.
Columns II and III of Figure 8
ntain the results of measurements
ade at X-band and S-band fre-
uencies utilizing the varactor diodes
the degenerate case of the para-
etric amplifier, i.e., the signal and
dler frequencies are identical or very

SEMICONDUCTOR REACTANCE DIODE AMPLIFIERS (PARAMETRIC AMPLIFIERS)

Made by:	H. Heffner & F. L. Kotzebue, Stanford Univ., Proc. I.R.E. Vol. 46 No. 6, p. 1301, Jun 58	G. F. Herman, M. Uenohara, A. Uhlir Proc. I.R.E. Vol. 45, p. 1301-2 June 1958 (BTL)	F. A. Brand, W. G. Matthei SigC, & T. Saad, Sage Labs.
Type Diodes	Germanium alloyed varactor diode (WE 427A)	Silicon diffused varactor diode M 2102 Germanium alloyed varactor diode (WE 427A)	2 silicon diffused varactor diodes (M 2102) frequency cutoff of diodes = 45 Kms/c
Amplifier: Type:	Parametric	Degenerate parametric	Degenerate parametric
Signal Frequency	1170 Mc/s	5850 Mc/s	2900 Mc/s
Pump Frequency	3480 Mc/s	11,700 Mc/s	5800 Mc/s
Pump Power	100 mw	1-500 mw	55 mw
Power Gain	40 db 19 db 10 db	45 db 18 db	19.2 db 33 db
Bandwidth	1 Mc/s 2.2 Mc/s	8 mc (at f_s = 5840 Mc/s)	½ Mc/s
Noise Fig. (System)			6 db (870°K) ($F_{receiver}$ = 20 db)
Noise Fig. (Amplifier)	4.8 db (580°K)	2 db (170°K) (degenerate parametric amplifier case)	2.7 db Te = 250°K
Dynamic signal range:	100 db		
Saturated power output:	1.5 mw		
Oscillator:			Observed but not measured
Input pump power	100 mw	10 mw	
Output pump power		1.4 mw	
Efficiency		14%	
Frequency	1200 Mc/s and 2300 Mc/s		
Other Conditions:	Reverse DC bias of 5 volts Room temperature operation Rectangular cavity (triply resonant) Idler Frequency: 2310 Mc/s	Ge (v-o) = 0.4 — 2.85 uuf Diffused diode=zero DC bias Alloyed diode = negative bias from 1 to 1.5 volts Room temperature operation	Hybrid mixer (no circulator necessary) Room temperature operation No DC bias

Figure 8

close in value. In the X-band receiver, a circulator was used, while in the S-band receiver none was needed because a hybrid (crystal holder) was utilized.

It is in this case that the lower-sideband is used in conjunction with the signal to give improved signal-to-noise performance. This type of operation, since it is 3 db better than a single "sideband" operation, should give a 3 db improved performance when incorporated in, for example, a search radar. If one assumes the case where the two frequencies are identical, it can be shown that if the incoming signal has a doppler frequency associated with it, then information directly proportional to twice the doppler frequency can be obtained by using this type of amplifier.[26]

It should be pointed out that one

TYPE: Traveling Wave Parametric Diode Amplifier
R. S. Engelbrecht (BTL)
Proc IRE, V46, #9, p 1655, Sept 1958

MATERIAL: Four Diffused-Junction Silicon Varactor Diodes (M2102)

AMPLIFIER: *Case 1*
Signal Frequency: 400 mc/s
Pump Frequency: 900 mc/s
Idler Frequency: 500 mc/s
Pump Power: 10 mw
Power Gain: 10 db Bandwidth: 100 mc/s
Noise Figure: 3.5 db (360°K)

Case 2
Signal Frequency: 380 mc/s
Pump Frequency: 630 mc/s
Idler Frequency: 250 mc/s
Pump Power: 1-2 mw
Power Gain (Forward — Signal and Pump Traveling in Same Direction): 12 db
Power Gain (Reverse — Signal and Pump Traveling in Opposite Direction): —3 to —6 db
Conversion Gain (380 to 250 mc): 10 db
Bandwidth: 10-20 mc
Noise Figure: 3.5 db (360°K)

OSCILLATOR: Noticed

OTHER CONDITIONS: Traveling Wave Structure
Room Temperature Operation

Figure 9

is not required to use a pump frequency which is equal to the sum of the signal and idler frequencies. Chang and Bloom[27] have shown that parametric type amplifiers can be constructed which utilize a relatively low-frequency pump. This fact is very significant in that it shows it is feasible to use, for example, a transistor(s) as the local oscillator (pump) and to have the signal and idler circuits at a microwave frequency.

Reactance diodes can be used in a slow-wave structure also, and one should expect to obtain high gain and large bandwidths by this method. R. S. Engelbrecht[28] has reported on such a structure which uses four diodes in a waveguide slow-wave structure. The data concerning this very important type of reactance diode amplifier is given in Figure 9. Of course, the significance of this data is in the large bandwidths that are obtained in conjunction with an appreciable amount of power gain. In addition, this device is non-reciprocal in that the signal power is lost when it travels through the device in the reverse direction.

It should be pointed out that while most of the published work on these reactance diode amplifiers has been at microwave frequencies, this is not the only frequency range where they work or where they will be of interest. On the contrary, low-frequency applications should materialize where diode reactance amplifiers will be the best amplifier available. As an example, B. Salzberg and E.

W. Sard[29] of Airborne Inst. Labs. have constructed a very low noise temperature (40°K) low frequency (1 mc) receiver using two semiconductor diodes (1N470) which were biased in the reverse direction, and were used as varactor diodes.

SUMMARY and CONCLUSIONS

The first nine figures summarize the state of the art today in these fields. It is clear that using one of these amplifiers, one would obtain an improved receiver performance. A familiar question one may be asked today is; which is the best, the maser, the ferrite amplifier, or the reactance amplifier? Before one can answer that question, certain boundary conditions must be established, such as what is the amplifier's intended use; what kind of system performance does one wish to obtain, etc.

Figure 10 lists criteria which probably influence an engineer's choice of amplifiers. One can safely say, however, that most of the emphasis in the field today is being placed on various types of semiconductor diode reactance amplifiers.

For the cases where extremely low system noise figures are needed, such as radio telescope radiometer, the solid state maser may be used to some advantage. In most applications, however, varactor diode amplifiers will be used.

What could one say about the future of this field? It is the author's belief that all three types of amplifiers probably could be made to give superior performance in almost every given specific situation if sufficient research and development work is expended in this area. But a more realistic approach leads the author to guess that at least 80 to 90 percent of present day and future applications will use the reactance diode type of amplifier.

In fact, the low-frequency use of diode amplifiers should become an extremely important area in electronics. Considering this statement and, meanwhile, recognizing that vacuum tube parametric amplifiers are also being developed, the author concludes that reactance diode amplifiers probably will, by far, be the most important of the newer amplifiers, and will be incorporated in most kinds of electronic equipment.

CRITERIA FOR CHOICE OF AMPLIFIER

Gain
Bandwidth (a) Instantaneous (b) Tunable
Noise Figure
Frequency Range of Operation
Dynamic Range and Level of Signal Input Power
Pump Power
Recovery Time Limitations
Operating Temperature Requirements
Magnetic Field Requirements
Use of Lower Frequency Pump Power
Stability with Various Parameters
Efficiency
Reliability
Size and Weight
Simplicity
Cost

Figure 10

ACKNOWLEDGMENT

The author wishes to express his appreciation to the many people who discussed various aspects of these amplifiers with him, and especially to F. A. Brand of USASRDL and R. Ryder, H. Seidel, and A. Uhlir of BTL for their very interesting comments concerning this work.

REFERENCES

1. N. Bloembergen, "Proposal for a New Type of Solid State Maser," Phys. Rev. Vol. 104, pp. 324-327, Oct. 1956.

2. H. Suhl, "Proposal for a Ferromagnetic Amplifier in the Microwave Range," Phys. Rev. Vol. 106, p. 384, Apr. 1957.

3. A. Uhlir, "Frequency Conversion and Computation with P-N Junction Devices," presented at the First Annual Technical Meeting of IRE-PGED at Washington, D.C. 24 Oct. 1955. Also Chapter 1, Sixth Interim Technical Report, "Crystal Rectifiers — Task 8," 15 June 1956, Signal Corps Contract DA 36-039 sc-5589.

4. A. E. Bakanowski, "Small-Signal Admittance Measurements for a Retarding Field Diode," Chapter 2, Ninth Interim Technical Report, "Crystal Rectifiers—Task 8," 15 Oct. 1956, Signal Corps Contract DA 36-039 sc-5589.

5. H. Suhl, loc. cit.

6. A. D. Burk, L. Kleinman, C. E. Nelson, "Modified Semi-static Ferrite Amplifier," paper presented at WESCON, 20 Aug. 1958.

7. H. E. D. Scovil, "The Three-Level Solid State Maser," IRE Transactions on Microwave Theory and Techniques, Vol. MTT-6 No. 7, pp. 29-38, Jan. 1958.

8. Mavar: An acronym for "Modulator Amplification by a VAriable Reactance."

Maser: An acronym for "Microwave Amplification by the Stimulated Emission of Radiation."

9. W. J. Giguere, "A Transistorized 150 mc FM Receiver," Proc. IRE, Vol. 46 No. 4, pp. 693-699, Apr. 1958.

10. G. C. Messenger, "New Concepts in Microwave Mixer Diodes," Proc. IRE, Vol. 46, No. 6, pp. 1116-1121, June 1958.

11. A. Uhlir, "Potential of Semiconductor Diodes in High-Frequency Communications," Proc. IRE, Vol. 46, No. 6, pp. 1099-1115, June 1958.

12. Ibid.

13. Loc. cit.

14. H. E. D. Scovil, G. Feher, and H. Seidel, "Operation of a Solid State Maser," Phys. Rev. Vol. 105, pp. 762-763, Jan. 1957.

15. E. O. Shulz — DuBois, "The Three Level Solid State Maser," Chapter 1, Sixth Interim Report on "Microwave Solid State Devices," 15 Aug. 1958, Signal Corps Contract DA 36-039 sc-73224.

16. Loc. cit.

17. P. K. Tien and H. Suhl, "A Traveling-Wave Ferromagnetic Amplifier," Proc. IRE, Vol. 46, No. 4, pp. 700-706, Apr. 1958.

18. M. T. Weiss, "A Solid State Microwave Amplifier and Oscillator Using Ferrites," Phys. Rev. V. 107, No. 1, p. 317, July 1957.

19. Loc. cit.

20. Loc. cit.

21. Loc. cit. (Footnote 11)

22. J. M. Manley and H. E. Rowe, "Some General Properties of Non-Linear Elements, Part I: General Energy Relations," Proc. IRE, Vol. 44, No. 7, pp. 904-913, July 1956.

23. H. E. Rowe, "Some General Properties of Non-Linear Elements, Part II Small Signal Theory," Proc. IRE, Vol. 46, No. 5, pp. 850-860, May 1958.

24. M. E. Hines, "Three-Frequency Theory of Amplification in Non-Linear Reactance Modulators," to be published.

25. Loc. cit. (Footnote 11)

26. The ideas in this paragraph were suggested to the author by Dr. R. Ryder (BTL) in a private communication.

27. K. K. N. Chang and S. Bloom, "Parametric Amplifier Using Lower Frequency Pumping," Proc. IRE, Vol. 46 No. 7, pp. 1383-1386, July 1958.

28. R. S. Engelbrecht, "A Low-Noise Non-Linear Reactance Traveling-Wave Amplifier," Proc. IRE, Vol. 46, No. 9, 1655, Sept. 1958.

29. B. Salzberg and E. W. Sard, "Low-Noise Wide-Band Reactance Amplifier," Proc. IRE, Vol. 46, No. 6, p. 130 June 1958.

* Paper presented at the "Electronic Warfare Symposium," 3 October 1958, University of Michigan, Research Institute Ann Arbor, Michigan.

USING THE SMITH DIAGRAM . . . I

y
EORGE C.
OUTHWORTH

In an effort to combine human interest with science, this Journal published in its very first issue some of the more important facts about Phillip H. Smith and the diagram for which he is so well known. This seemed very appropriate, for the Smith diagram has proved through the years to be one of the more useful tools of microwave technology. In the second issue of the Journal there was published a more complete account giving some of the history of this diagram as well as the enumeration of the various problems that may be solved by its use. So much has now been said about the merits of this diagram that more information seems to be in order about: (1) How is the Smith diagram put together? (2) How does one solve problems by its use? These are the main objectives of the present article.

ansmission Lines

The term transmission line at one ne referred almost exclusively to a ir of conductors extending from e point to another. Often the disnce was tens or even hundreds of iles. The term now includes not ly these structures but many deces that were almost unknown a uple of decades ago. For example, transmission line may now be a llow metal pipe a few inches long, it may be a dielectric wire surunded by a metal sheath, or it ay be simply a dielectric wire th no metal of any kind present. ne essential of a transmission line ems to be that it be able to propate wave power from one point to other. In addition, it should share e properties of the type of line e have known for so many years; mely, it should have an identifile *characteristic impedance* K and a *opagation constant* γ complete with component *attenuation constant* α d a component *velocity constant* β. s in ordinary standard transmission ne practice, $\gamma = \alpha + i\beta$. The Smith agram provides suitable coordinates r plotting both attenuation constant d velocity constant in their proper lationships with other constants of e line.

As we shall see, localized impeances (or admittances) may be aced at the receiving end of the line provide a wide range of reflections. hese terminal impedances are often ferred to as *loads* in contrast with e primary source of power which is ten referred to as the *generator*. The tal load impedance may on occaon consist of several component imedances either in series or in parallel, d they may be spaced by significant ngths of transmission line. The latt plan in particular has had very

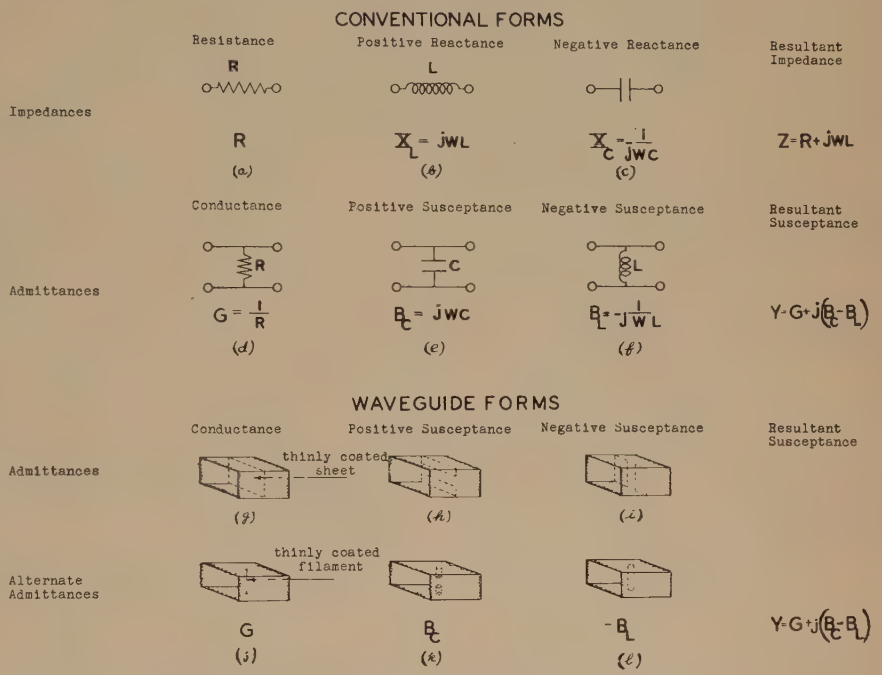


Figure 1 — Representative impedances and admittances serving as reflectors on transmission lines.

useful applications. They have had the effect of translating up the frequency scale techniques that were one time applicable only to relatively low frequencies. Much of our modern microwave technique is built around these methods. Illustrative examples will follow.

Some Common Impedors

In the earlier years of transmission line practice it was common to assemble load impedances from suitable resistances, inductances and capacitances of conventional design; i.e., carbon rods, coils wound from copper tubing, and air-spaced multiple plate condensers. These were the best approximations that could be had at the time. Units of this kind are shown in highly schematic form in the first and second rows of Fig. 1. With the advent of the waveguide, impedors of conventional design were no longer feasible, but there were evolved other arrangements that performed quite similar functions. Representative examples appear in the third and fourth rows of Fig. 1. Though the irises there shown bear little resemblance to their inductive and capacitive counterparts in the earlier rows, their performance is quite similar.

Often the individual units comprising the load are placed in series, as might be done with the arrangements shown in the top row, to provide an impedance $Z = R + iX$ where R is the resistance and X is the *reactance*. The term $i = \sqrt{-1}$ signifies that R and X are two mutually perpendicular vectors and that their resultant Z has the magnitude of $\sqrt{R^2 + X^2}$ for the series arrangement.

The quantity $X = \omega L - \frac{1}{\omega C}$.

Even more often the various impedance units may appear in parallel, as suggested by the second row of Fig. 1. In this case reciprocals of resistance and reactance are added to provide a resultant known as *admittance.* It is expressed by $Y = G + iB$ where $G = \frac{R}{R^2 + X^2}$ is the real part and is known as the *conductance* and $-B = \frac{X}{R^2 + X^2}$ is the imaginary part and is known as the *susceptance.* The Smith diagram provides a special grid on which we may plot either impedance or admittance and convert very simply from one to the other. The conversion is complete even to the point of specifying conductance G in terms of resistance R and the susceptance B in terms of the reactance X. The diagram also distinguishes between positive (inductive) reactances and negative (capacitive) reactances.

The Transformer Property

One of the more useful properties of a transmission line is its ability to transform an impedance Z(1), located at its terminus, into another impedance Z(0) as viewed at an earlier point along the line. See Fig. 2. Thus the transmission line may serve as a transformer. It is at its best when the line losses are low. As we shall see, this property enables us to derive, for a variety of practical uses, any of a wide range of useful impedances — sometimes pure resistances, sometimes pure reactances, both positive and negative, and sometimes various combinations of both resistance and reactance.

At this point we shall introduce some very useful ratios. They are obtained by dividing the various impedance components by the characteristic impedance K of the line to which they may be connected. These ratios are defined by

$$\overline{Z} = \frac{Z}{K}, \quad \overline{R} = \frac{R}{K}, \quad \text{and} \quad \overline{X} = \frac{X}{K}$$

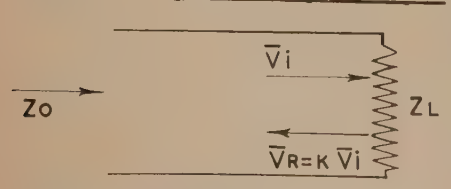


Figure 2—A transmission line terminated in an impedance Z.

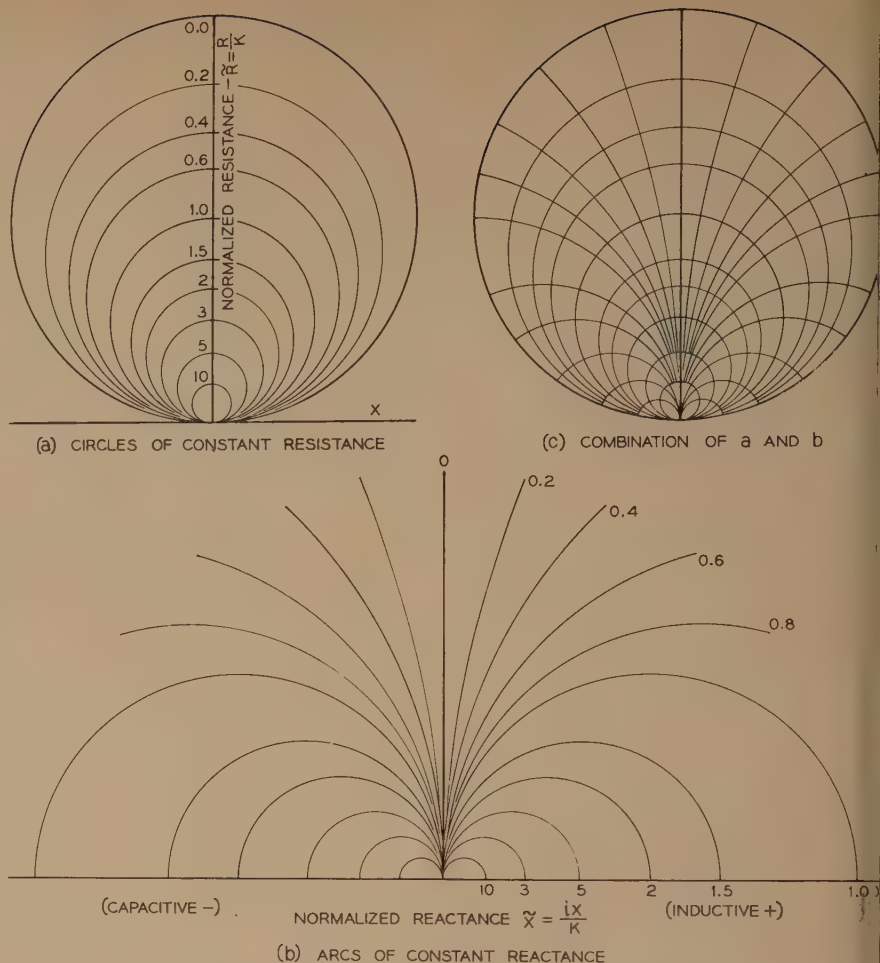


Figure 3 — Impedance grid of the Smith Diagram — used for representing the resistance and reactance components in line terminations.

Similar ratios are

$$\overline{Y} = \frac{Y}{M}, \quad \overline{G} = \frac{G}{M}, \quad \text{and} \quad \overline{B} = \frac{B}{M}$$

where $M = \frac{1}{K}$ is the *characteristic admittance* of the line. The use of these six ratios facilitates very materially the solution of transmission line problems both by mathematical processes and by graphical methods. These ratios are sometimes referred to as *normalized values* of impedance, resistance, and reactance, as well as corresponding normalized values of admittance, conductance, and susceptance.

According to accepted mathematical procedure, a normalized impedance $\overline{Z} = \frac{Z}{K}$, when connected at the receiving end of a line of length l, will appear at the input end, designated as point zero as

$$Z(0) = \frac{\overline{Z}(1) + \tanh\left(\alpha l + i\frac{2\pi l}{\lambda}\right)}{1 + \overline{Z}(1)\tanh\left(\alpha l + i\frac{2\pi l}{\lambda}\right)} \qquad (1)$$

where α is the attenuation constan measured in nepers per meter and is the wavelength measured in m ters. The expression tanh refers t the hyperbolic tangent. It is som what similar to the correspondin trigonometric function but is f more involved. Such functions a avoided by the use of the Smit diagram.

If one specifies the load at th point l in terms of the normalize admittance $\overline{Y}(1) = \frac{Y(1)}{M}$ where M the characteristic admittance of th line, then

$$Y(0) = \frac{\overline{Y}(1) + \tanh\left(\alpha l + i\frac{2\pi}{\lambda} l\right.}{1 + \overline{Y}(1)\tanh\left(\alpha l + i\frac{2\pi}{\lambda} l\right.} \qquad (2$$

If in either of the above equation one substitutes numerical values Z(1) or Y(1) with correspondin values of α and l, one obtains th impedance Z(0) or admittance Y(as viewed from the input end. A we shall see, it is very easy to car out this process with an accura

ufficient for most purposes by means f the Smith diagram. These readily vailable impedances are used ex- ensively in microwave practice.

Reflections in Uniform Transmission Lines

In Fig. 2, let V_i, V_r, and V_t be respectively the incident, reflected, and otal or transmitted voltage appearing across the normalized load impedance $\overline{Z}$ placed at the end of a ransmission line. Similarly, let I_i, $_r$, and I_t be the corresponding currents through the normalized load impedance. Then for continuity

$$V_i + V_r = V_t \text{ and } I_i + I_r = I_t \tag{3}$$

he corresponding coefficients of reflection q_i and q_v of current and oltage are

$$q_i = \frac{I_r}{I_i} = \frac{1-\overline{Z}}{1+\overline{Z}} = \frac{\overline{Y}-1}{\overline{Y}+1} \tag{4}$$

nd

$$q_v = \frac{V_r}{V_i} = \frac{\overline{Z}-1}{\overline{Z}+1} = \frac{1-\overline{Y}}{1+\overline{Y}} \tag{5}$$

t is also true that the magnitude of he voltage reflection coefficient is iven by

$$|q_v| = \sqrt{\frac{(Z^2+1)+2\overline{Z}\cos\phi}{(Z^2+1)-2\overline{Z}\cos\phi}} \tag{6}$$

where ϕ is the angle whose cosine is

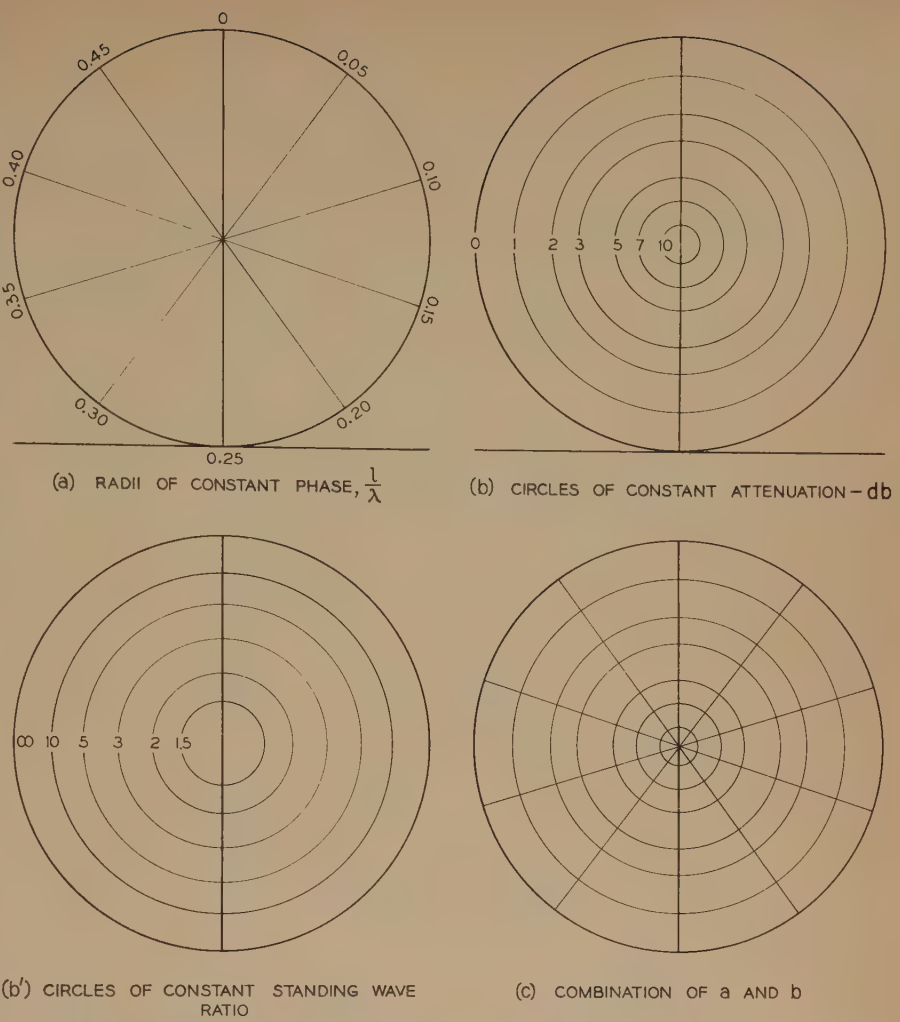
$$\frac{\overline{R}}{\overline{Z}}$$

Another relation of significance is

$$\tan\phi = \frac{2|\overline{Z}|\sin\phi}{\overline{Z}^2-1} \tag{7}$$

where ϕ is the *angle of the reflection oefficient.* It is a measure of the disance from the end of the line to the irst voltage minimum. Both the magnitude and the angle of the reflection oefficient may be read from the Smith liagram.

Because waves of voltage (or current) may be reflected by a load, it is ossible to have on the line, waves noving in opposite directions. One et is associated with the source while he other is associated with reflection. As might be expected, the two sets of vaves interfere to produce at points vhere the two waves are in opposite hase, minima in the resultant wave nd at other points along the line vhere the two components arrive in he same phase, maxima in the reultant wave. This phenomenon is nown generally as standing waves and he minima and maxima are often eferred to as nodes and loops. If the



(a) RADII OF CONSTANT PHASE, $\frac{l}{\lambda}$

(b) CIRCLES OF CONSTANT ATTENUATION – db

(b') CIRCLES OF CONSTANT STANDING WAVE RATIO

(c) COMBINATION OF a AND b

Figure 4 — Propagation grid of the Smith Diagram — used for representing the relative phase and attenuation along a transmission line.

reflection coefficient is high; i.e., $q_v = 1$, the minima may be substantially zero while the maxima may be substantially twice the amplitude of the incident wave. The ratio of the maximum to the minimum in the standing wave is a very significant quantity expressed by the relation:

$$|\Psi_v| = \frac{1+|q_v|}{1-|q_v|} \text{ and}$$

$$|\Psi_i| = \frac{1+|q_i|}{1-|q_i|} \tag{8}$$

The ratio of maximum to minimum is also known as *standing wave ratio* and is often designated as S.W.R. This is another of the quantities that may be related to other significant quantities by the Smith diagram. Sometimes the apparatus used in measuring standing wave ratio is calibrated in relative power. In this case:

$$\Psi_w = |\Psi_v|^2 = \left\{\frac{1+|q_v|}{1-|q_v|}\right\}^2 \tag{9}$$

At this point, we shall show the construction of the various Smith grids and follow with certain numerical examples.

The Smith Grid

Referring to Equation 1, it will be noted that the quantities $\overline{Z}(0)$ and $\overline{Z}(1)$ represent two localized impedances that may appear at the two ends of a transmission line, whereas the quantities αl and $i(2\pi/\lambda)l$ represent two characteristics of the line itself. It is the function of the impedance diagram to interrelate these two pairs of quantities. As we shall presently see, this is accomplished by means of two properly proportioned coordinate systems, one superimposed on the other. These will be examined separately.

The particular coordinate system representing the localized impedances is made up of lines of constant resistance $\overline{R}$ (or conductance $\overline{G}$), and lines of constant reactance $\overline{X}$ (or susceptance $\overline{B}$). The first are circles of radius $1/(1+\overline{R})$ with their centers on the resistance axis and all tangent at the intersection of the resistance and reactance axes as shown in Fig. 3(a). The second are also circles, but each

has a radius of $1/\overline{X}$ and each has its center along the reactance axis as illustrated in Fig. 3(b). In this case also the circles are all tangent at the intersection of the two axes. The circles to the right of the axis of resistance correspond to positive reactance (or susceptance) while those to the left correspond to negative reactance (or susceptance). These two families of circles, when superimposed one on the other as illustrated in Fig. 3(c), constitute the working grid.

In the Smith chart, electrical distance $(2\pi/\lambda)l$ (or more particularly l/λ) is laid off as an angle subtended by a radius vector rotating clockwise about a common center as illustrated in Fig. 4(a). It will be seen that a complete revolution of the radius vector corresponds to a distance measured along the transmission line of one-half wave. The quarter-wave relationship so common in transmission-line work therefore corresponds to a half-revolution. In this coordinate system attenuation αl is measured along the radius vector. Hence lines of constant attenuation are concentric circles as illustrated in Fig. 4(b). As will be noted, they become progressively closer as one passes from the outside toward the center. The particular coordinate system that represents the characteristics of the line is obtained by superimposing Fig. 4(a) on Fig. 4(b). The result is shown in Fig. 4(c).

As already pointed out, the Smith chart is obtained by superimposing Fig. 3(c) on Fig. 4(c) and when this is done it becomes possible to interrelate very simply all of the four quantities appearing in Equation 1. The procedure by which this may be accomplished will be illustrated presently by a few numerical examples.

In carrying the foregoing method into practice, it is not always feasible to include on the chart all of the lines of the two superimposed coordinate systems. To do so might lead to a confusion of lines and also to error. To avoid this possibility, certain of the lines of the second system are either omitted or appear in highly abbreviated form. For example, the scale of electrical distance [radial lines of Fig. 4(a)] may appear only at the periphery of the diagram. If the remaining portions are needed, they may be located very simply by means of a straightedge. Sometimes the straightedge is a rotatable arm pivoted at the center. Similarly the circles of constant attenuation may be replaced by a single linear scale located adjacent to the diagram from which suitable values may be transferred as needed. Sometimes this attenuation scale is mounted on the rotatable arm.

It is of interest that a simple extension of the impedance diagram makes it possible to scale off with good accuracy the magnitude of the *standing wave ratio*. For this purpose it is merely necessary to add another series of concentric circles as illustrated in Fig. 4(b′). Their magnitudes begin at zero at the center and extend to infinity at the periphery of the diagram. As in the case of circles of constant attenuation, so also circles of constant standing wave ratio are usually omitted from the chart itself. As before, their corresponding values may be transferred from a near-by scale or the scale may be mounted on the rotatable arm.

There is still another useful scale that may be incorporated in the impedance diagram. This makes it possible to obtain values of reflection coefficient corresponding to the values of standing wave ratio just referred to. This scale is a third set of circles similar to the circles of standing wave ratio shown in Fig. 4(b′) but beginning with zero at the center of the diagram and ending with unity at the periphery. Like the circles already referred to, the circles of constant reflection coefficient are usually omitted from the chart itself. Again corresponding values of reflection coefficient may be transferred from a near-by scale or the scale may be mounted on a rotatable arm. A scale of angles arranged around the periphery of the diagram make it possible to determine angles of reflection coefficient. This scale begins at zero at the bottom of the figure (intersection of the resistance and reactance axes) and increases in both positive and negative values to 180 degrees at the top.

Numerous examples of the Smith chart appear in the text that follows. Mostly, however, they represent a highly simplified form, designed particularly for demonstration purposes. A form containing more lines and sufficiently accurate for most engineering problems is available as graph paper. Still another form made of white plastic and carrying a rotatable arm complete with scales is sold under the name of "Transmission-Line Calculator."[1]

Numerical Examples

(1) As a particularly simple example illustrating the use of the impedance diagram, let it be assumed that a pure resistance having a normalized magnitude 2 is connected at the output end of a dissipationless transmission line and one wishes to know the various impedances seen at the input as the length of the line is indefinitely increased. For a dissipationless line, it may be assumed that a wave traveling in the direction of increasing distance is unattenuated and similarly a wave traveling in the opposite direction is likewise unattenuated. The standing wave resulting from these two components therefore, may be assumed to be constant in its average amplitude at all points along the length of the line.

Since, in this problem, the output impedance normalized is $\overline{Z}(1) = 2 + i0$, it appears on the chart of Fig. 5 as point p_1. The voltage standing wave ratio for this case may be calculated by means of Equation 5. But more simply, it may be transferred from the scale at the top of Fig. 4 and may be found to be 2. A circle of constant standing wave ratio of this magnitude is shown drawn through point p_1.

In the Smith chart, distance measured along a transmission line from the load back toward the generator corresponds to a clockwise rotation around the diagram, and, for the dissipationless case, the circle of constant standing wave ratio $a_1 b_1 c_1 d_1$ is the locus of all possible values of impedance as seen from the input end of the line.

Beginning at point p_1 and progressing clockwise around the circle $a_1 b_1 c_1 d_1$, the normalized input impedance first appears as a resistance only slightly less than 2 in series with a small negative reactance (capacitance). Continuing further the resistance decreases while the negative reactance increases until, at some point just before b_1 is reached, the magnitude of the latter is a maximum. It is to be noted that at point b_1 the resistance term is unity and is decreasing. Continuing still further both the resistance and negative reactance decrease until at point c_1 which is a quarter-wave removed from the load, the resistance is a minimum and the reactance is zero

1. Both the paper and the calculator are available at most of the larger university book stores of the country.

will be noted that the quarter-wave
ne has had the effect of transform-
g a terminal resistance (normal-
ed) of magnitude 2 into an input
sistance of magnitude ½. Con-
nuing still further around the cir-
e which corresponds to a still fur-
er extension in the length of the
nnecting line, the reactance term
comes positive (inductance), in-
easing to a maximum at a point
st beyond d_1. In the meantime the
agnitude of the resistance term has
en increasing, having passed at
a value of unity. Finally, at a
oint one-half wave from the load,
e return to point a_1 where the
iginal impedance again prevails.
hus it will be seen that the half-
ave line has had the effect of dis-
lacing the load in space without al-
ring its apparent impedance.

Extending the length of the dissi-
ationless line beyond a half wave
rries the operating point on the
art from a_1 onward toward b_1 and
ence to c_1, d_1, and again back to
. If the line is dissipationless, this
ay be continued indefinitely, ob-
ining, in each half-wave section,
l of the normalized impedances
ecified by the circle of constant
anding wave ratio $a_1 b_1 c_1 d_1$.

It should be noted that two points
revail in each half-wave section
here the input impedance is a pure
sistance. One, a_1, is greater than
aracteristic impedance while the
her, c_1, is less than characteristic
npedance. These two points have
ecial significance as we shall later
e. The former corresponds to a
oint in the standing wave where the
oltage is a maximum while the
tter corresponds to a point where
e voltage is a minimum. As will be
oted, $\overline{R}_{max} \cdot \overline{R}_{min} = 1$. Two other
oints on this circle are also of spe-
al significance. They are points b_1
nd d_1 where the resistance compo-
ent is unity. This suggests that, if
either of these points on the trans-
ission line, an appropriate compen-
ting reactance were introduced, the
perating point would be displaced
n the chart from b_1 (or d_1) to the
nter of the diagram and accord-
gly a match would be effected. This
true, as we shall later see.

It will be noted from Fig. 5 that,
a proper choice of length of line,
oth positive and negative reactances
ay be provided, but there also must
revail a resistance component hav-

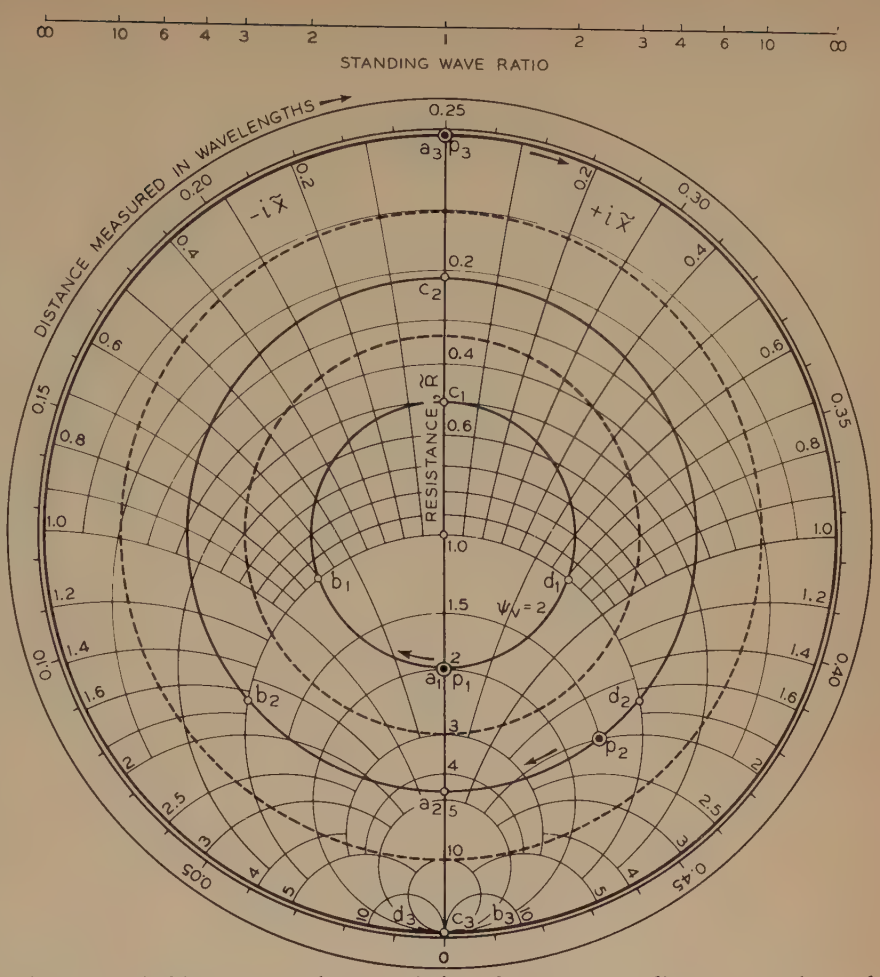


Figure 5 — Smith Diagram showing circles of constant standing wave ratio, each corresponding to a particular terminal impedance.

ing a magnitude lying between the limits of $\overline{R}$ and $\frac{1}{\overline{R}}$

An inspection of Fig. 5 will show that if input impedances are wanted having a larger range of resistances than specified by the circle $a_1 b_1 c_1 d_1$ they may be had by increasing the normalized resistance appearing at the terminal. The loci of possible input impedances for the particular cases in which the normalized terminal resistances are 3 and 10 respectively are shown as dotted lines.

(2) As a second numerical problem, assume that the impedance placed at the end of the dissipationless line is specified by $\overline{Z} = 1.5 + i2$. This is represented by point p_2 in Fig. 5 and as before it gives rise to a standing wave, this time represented by the circle $a_2 b_2 c_2 d_2$. The magnitude of the standing wave may be read, as before, from the attached scale or it may be calculated. It will be noted that, after an initial length of line ($p_2 a_2$) of approximately 0.051λ has been added, point a_2 is reached where the input impedance again appears as a pure resistance. Its normalized magnitude is approximately 4.6. At another point c_2 a quarter wave further on, the input impedance again appears as a pure resistance but this time its normalized value is approximately 0.22. Between these two points along the line there may appear, for various lengths, input impedances as specified by the locus $a_2 b_2 c_2 d_2$.

(3) As an extreme case, it may be assumed that the impedance appearing at the end of the transmission line is zero. This corresponds to a point p_3 on the chart, and this time the path is $a_3 b_3 c_3 d_3$. Since the latter carries us around the periphery of the diagram, it provides thereby impedances that vary from nearly zero resistance and zero reactance at a_3 to extremely large values of both resistance and reactance at points near $b_3 c_3 d_3$. This condition will be recognized as comparable with that of a tuning stub. In that case, the standing wave ratio is infinite, and the input impedance is, except for small regions, a pure reactance extending from near zero to almost infinity.

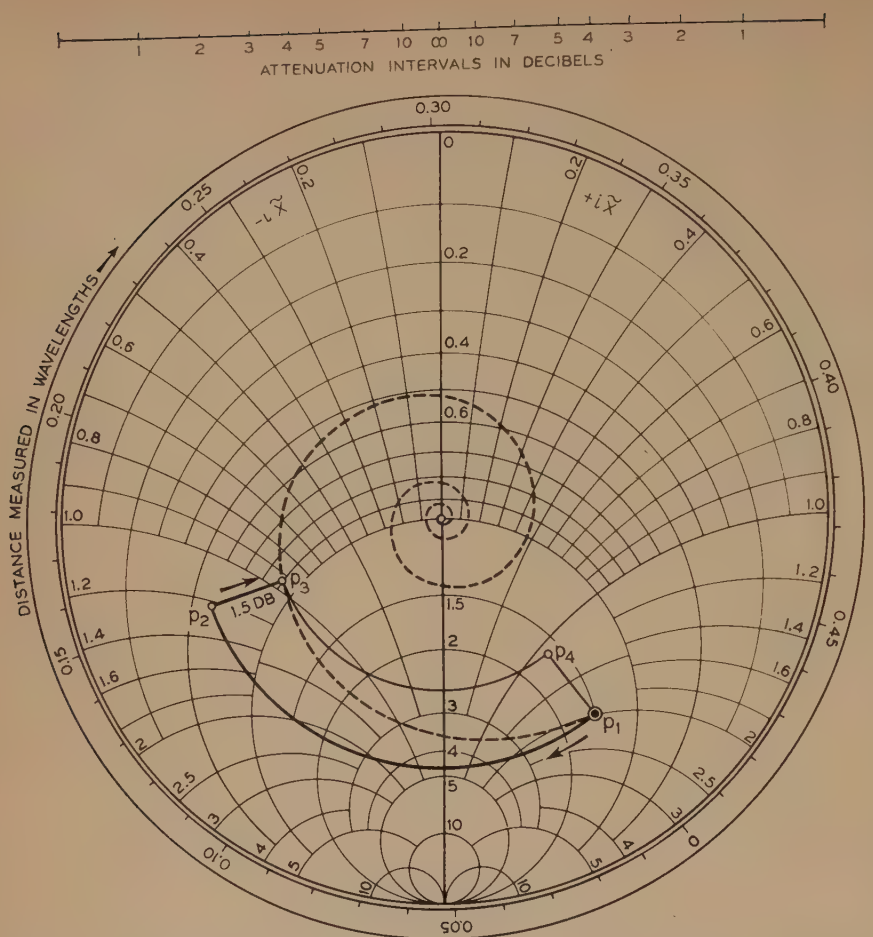


Figure 6 — Smith Chart showing effect of attenuation on input impedance of a transmission line. If the line is infinitely long the locus of impedances spirals to the center of the figure. If the line is of infinite length it may spiral to some point P_3.

It is hardly necessary to note in passing that, if the line assumed above had been terminated in its characteristic impedance, $\overline{Z}(1) = 1 + i0$, the plotted points a b c d, etc., would all have appeared at the center of the chart which corresponds to a condition of match.

(4) As a fourth example, let it be assumed that the transmission line gives rise to attenuation and we wish to know its effect on the input impedance for various lengths of line. If dissipation prevails in a transmission line, the component wave leaving the input is attenuated as it travels toward the distant end and again as it returns after reflection. It should be evident that the standing wave resulting from these two components varies in amplitude from point to point along the line. Furthermore, the standing wave and also the input impedance as seen from the transmitting end both decrease as the length of the line is increased. If the length of line is very great or the attenuation constant is correspondingly large, the returning wave will be very small and the line will appear to be terminated in its characteristic impedance. In view of these facts, it may be expected that the path of the operating point on the impedance diagram will spiral inward toward the center of the figure perhaps as illustrated by the locus p_1 p_3, etc., in Fig. 6. In this case, a rather large attenuation of 10 db per unit length of line has been assumed. In this instance the unit of length is one wavelength. This corresponds to a spiral on the diagram of 5 db per revolution.

In carrying this method into practice, it is not necessary to plot the locus of impedances as might be inferred from the preceding discussion. The reasons will be evident shortly. To illustrate the procedure actually followed in solving numerical problems, let it be assumed that a line having characteristics identical with that just discussed is 0.15 wavelength long and that it is terminated in an impedance of $\overline{Z}(1) = 1.5 + i2$. This value is plotted as p_1 in Fig. 6. For this particular length of line, the total attenuation will amount to 1.5 db.

From the scale of attenuation a the top of the figure, it is found tha p_1 lies on a circle of constant attenu ation corresponding to a value c about 2 db. This circle is represente by the arc p_1 p_2. Since the line give rise to an attenuation of 1.5 db, w now know that the input impeda ance when found will correspon to a point on another circle of cor stant attenuation of 1.5 db highe level. This 3.5 db level is represente by the arc of the circle p_3 p_4. W may now lay off on the scale aroun the periphery of the diagram length of line of 0.15 wavelengt and readily find the point p_3. Thi specifies the input impedance for th particular case assumed. Its coord nates are approximately $\overline{R} = 0.8$ and $\overline{iX} = -0.93$.

To reach p_3 one may imagine th operating point having moved alon the dotted spiral from p_1 to p_3. How ever, a procedure easier to carry int practice is to regard the operatin point as having moved from p along a circle of constant attenuatio a distance of 0.15 wavelength to p and thence along the radius cor sponding to the transmitting end c the line a distance of 1.5 db to p Alternatively the operating poin may be regarded as having move from point p_1 along the radius co responding to the terminus of th line a distance of 1.5 db to point p and thence, along a circle of constan attenuation, a distance of 0.15 wave length to p_3.

It will be noted in passing that p corresponds to the input impedanc that would have prevailed if the lin had been dissipationless. Its coord nates are approximately $\overline{R} = 0.6$ and $\overline{iX} = -1.2$. A comparison c points p_2 and p_3, as one imagine the length of line indefinitely in creased, may help the reader to visu alize the effect of attenuation on in put impedance.

(5) The practical use of the Smit diagram is not limited to a scaling c the relations between $\overline{Z}(0)$, $\overline{Z}(1$ α, and β. It yields a number of oth important facts as well. Among thes are the various relationships inc dental to compensating for a reactiv discontinuity that may inadvertent have been introduced into a line. Th discontinuity, for example, may ha been due to a bend in the line perhaps to a sharp kink in one of two wires. In one case the result

though an element had been con-
cted across the line and in the
er it is as though the element were
series. It is assumed that the line
ond the discontinuity is other-
se uniform and is terminated in its
racteristic impedance. Certain
ts relating to a discontinuity of
s kind and to its compensation
depicted in Fig. 7.

In order to make the problem def-
te, let it be assumed that an im-
dance $\overline{Z} = 0 + i2$ is placed in
ies with the line. It will be seen
t the introduction of this im-
dance together with the character-
ic impedance of the line beyond
s had the effect of terminating the
e in a normalized impedance of
$= 1 + i2$. This, in turn, is equiva-
t to shifting the operating point
m the center of Fig. 7 to point p
ere $\overline{Z} = 1 + i2$. From the scale
ve we find that this corresponds
a standing wave ratio of about Ψ_v
6. Increasing the distance along
connecting line between the load
d the point where observations
made causes the operating point
move clockwise along the circle
constant standing wave ratio from
int p through point a where the
ltage of the standing wave is at a
ximum to a point b where the load
transformed to a value of
$= 1 - i2$. If at this point, a second
ctance of $\overline{X} = 0 + i2$ is connected
o the line, the operating point
ll have been transferred from b
k to the center of the figure, and
line with its two discontinuities
ll now appear matched. Alterna-
ely we may not place the compen-
ing reactance at the point just sug-
sted, but instead we may lengthen
line still further corresponding
a path on the diagram through b
d c to a point d identical with p
ere the input impedance is again
$= 1 + i2$. This time for match
must add a reactance $\overline{X} = 0 - i2$.
reasing the length of the line in-
finitely would return us, of course,
peatedly through points b and d.
us we see that there are two pos-
le points b and d at which the
d is transformed to an impedance

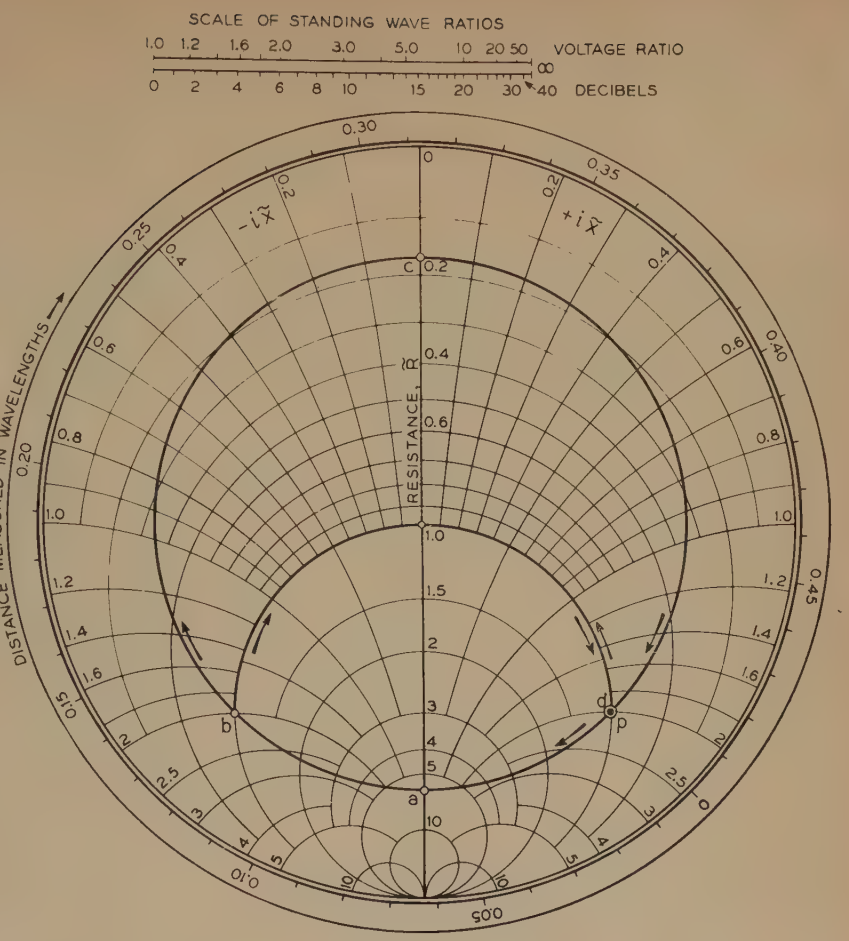


Figure 7 — Smith Chart showing how a series discontinuity $\overline{B} = i2$ (.d) may be compensated by a second discontinuity $\overline{B} = i2$ (.b) thereby making the line appear electrically smooth.

having a normalized resistance component of unity. These are significant points; for, at either, matching becomes a simple matter of introducing an appropriate compensating reactor.

Although in problem (5), we have assigned an arbitrary impedance of magnitude $\overline{Z} = 0 + i2$ to the original discontinuity, a knowledge of this quantity is not essential. Often measurements of standing wave ratio are made which not only establish the radius of the circle p a b c but the position of the first voltage maximum locates point a. The latter may then be used as a datum point in lieu of p. Having located a it is necessary only to proceed along the circle of constant standing wave ratio to point b where the normalized resistance is now unity. The reactance necessary for match may now be read from the impedance diagram.

The example cited relates to a reactance inserted in one leg of a two-wire transmission line. In many waveguide problems, the discontinuity is due to an admittance placed "across" the line. As already suggested, these problems may also be solved by the Smith diagram using a procedure almost identical with that just outlined. Because admittance diagrams, as contrasted with impedance diagrams, play such an important role in waveguide problems, their consideration will be deferred to an article appearing in the next issue of this Journal. In the article that follows there will appear, not only further exercises in the use of the Smith diagram, but there will be included the analyses of certain well-known microwave elements such for example as matching networks and frequency filters.

We are grateful to the D. Van Nostrand Co., Inc. for the use of material in this article drawn from the book, PRINCIPLES AND APPLICATIONS OF WAVEGUIDE TRANSMISSION, authored by Dr. George C. Southworth; and to the Bell Telephone Laboratories for the use of their material.

PART TWO OF DR. SOUTHWORTH'S PAPER ON THE USE OF THE SMITH CHART WILL APPEAR IN OUR NEXT ISSUE.

College Training in Microwave Engineering in America[1]

By CHARLES SÜSSKIND
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BERKELEY, CALIF.

University of California (Berkeley) is one of the American colleges at which instruction and research in microwave engineeri constitute a major part of electrical engineering activities.

The following observations are based on the results of a survey conducted by the writer in an effort to establish the scope of college-level instruction in microwave engineering and to estimate the rate at which the subject has been entering the curricula of American engineering schools.

The survey was the outgrowth of an earlier one,[2] in which graduate curricula in electrical engineering were reviewed and certain educational trends were noted. In the earlier survey, some thirty electrical-engineering topics were listed by the various institutions as fields of specialization, but the answers could not be readily interpreted to provide any information regarding the degree of specialization or the development of the several subjects.

In the present survey, an attempt to obtain such information in a statistically significant form was made by selecting one of these subjects — microwave engineering — and making a detailed inquiry into its history and present status in engineering education. Many of the findings can be doubtless extended to apply to any engineering specialty, so that this procedure may be considered as being equivalent to a poll of a representative sample of engineering educational institutions. The subject selected for this particular sampling was picked partly because of the author's personal interest in it, but also because it represents an important new field that is fairly young— and yet has been with us long enough to become firmly established in the college curriculum.

Institutions Polled

Questionnaires asking for information regarding courses and enrollments in the pertinent subjects, laboratory facilities, textbooks prescribed and recommended, etc., were sent to 152 institutions offering degrees in electrical engineering, of which 135 have curricula approved by the Engineers' Council for Professional Development (ECPD Fully 147, or 97 per cent, returne the filled-in questionnaires. A pr liminary evaluation quickly showe that from the viewpoint of instru tion in microwave engineering, ea reporting institution could be rea ily assigned to one of three group

GROUP I: Several courses sp cifically devoted to microwaves, ma ing up a considerable portion of t total electrical-engineering progra 10 institutions.[3]

GROUP II: One or two micr wave courses, usually with small e rollments, and constituting a re tively small portion of the over-a program. 62 institutions.[4]

GROUP III: No courses devot entirely to microwaves. 75 insti tions.

No Special Courses at Most Schoo

The size of Group III is one the more interesting results of t survey: more than half of the el trical-engineering departments

merica have scheduled no courses
mprising exclusively topics in mi-
owave engineering. (This group
cludes 11 of the 17 reporting in-
itutions with curricula not ap-
roved by ECPD.) About half a
ozen are planning to offer such a
urse within a year or two, and a
w belong to universities at which
zable microwave programs are be-
g carried on by the physics depart-
ent (e.g., Alabama and Duke).

Virtually every school in this
roup has a place for microwave
pics somewhere in its curriculum.
ccording to replies to one part of
he questionnaire, more than half
each the subject as a "predominant
art of one or more electronics
ourses," either on the undergradu-
te or graduate level; most of the
thers teach microwaves as a "minor
art of one or more electronics
ourses," and only a handful "not
t all." There is some evidence, from
eplies to a question inviting com-
nents, that several of the EE depart-
nents in Group III have deliberately
voided setting up a separate micro-
vave-engineering course. The com-
nents, which range in tone from
pologetic to irascible (". . . do not
pprove such a division on a fre-
uency basis — poor way to teach
. ."), make it obvious that not all
he institutions in Group III are in
his group solely because of a lack of
acilities or qualified teaching per-
onnel, although this appears to be
he case for most of them.

Degree of Specialization

The remaining schools (Groups I
nd II) appear to have not only rec-
gnized the various advantages of
eaching microwave engineering as
separate subject but — what is per-
aps more important — they were
ble to achieve this separation by
irtue of superior facilities and larger
udgets. It is certainly no coinci-
lence that Groups I and II com-
rise a far greater number of the
arger engineering colleges than
Group III, which consists predom-
nantly of smaller and less well-estab-
ished institutions. The size or total
ndowment of the institution are not
lways the significant factors in this
espect, to be sure; but the replies
o a question asking for an estimate
f the dollar worth of test equip-
ent used in the instruction labora-
ories for (a) general electronics and (b) microwaves actually show that the EE departments of the schools in Groups I and II are on the whole much better endowed than those in Group III.

Nevertheless, whether an institution falls into Group I or II does not appear to depend on size alone (though all schools in Group I have large enrollments and very good engineering facilities), but rather on several other factors that may or may not be the corollaries of large size, such as the availability of faculty members who have the training and the inclination to specialize in the particular subject; the extent of sponsored research in the department and elsewhere in the institution; and the history of the department (i.e., how soon the subject was established). A comparison of the institutions in the top group with those in Group II suggests strongly that the development of a highly specialized program in microwave engineering (and, by inference, in any other specialty) can be related to factors such as the above, and may be hence influenced to a considerable extent by departmental policy on hiring, soliciting research funds, and adjusting curricula to new demands.

The higher degree of specialization does not manifest itself solely in the larger number of courses devoted to the subject, but also in the manner in which the subject is taught. The present survey sought to obtain a measure of the degree of sophistication of the instruction by listing 10 textbooks on microwave theory and measurements and asking

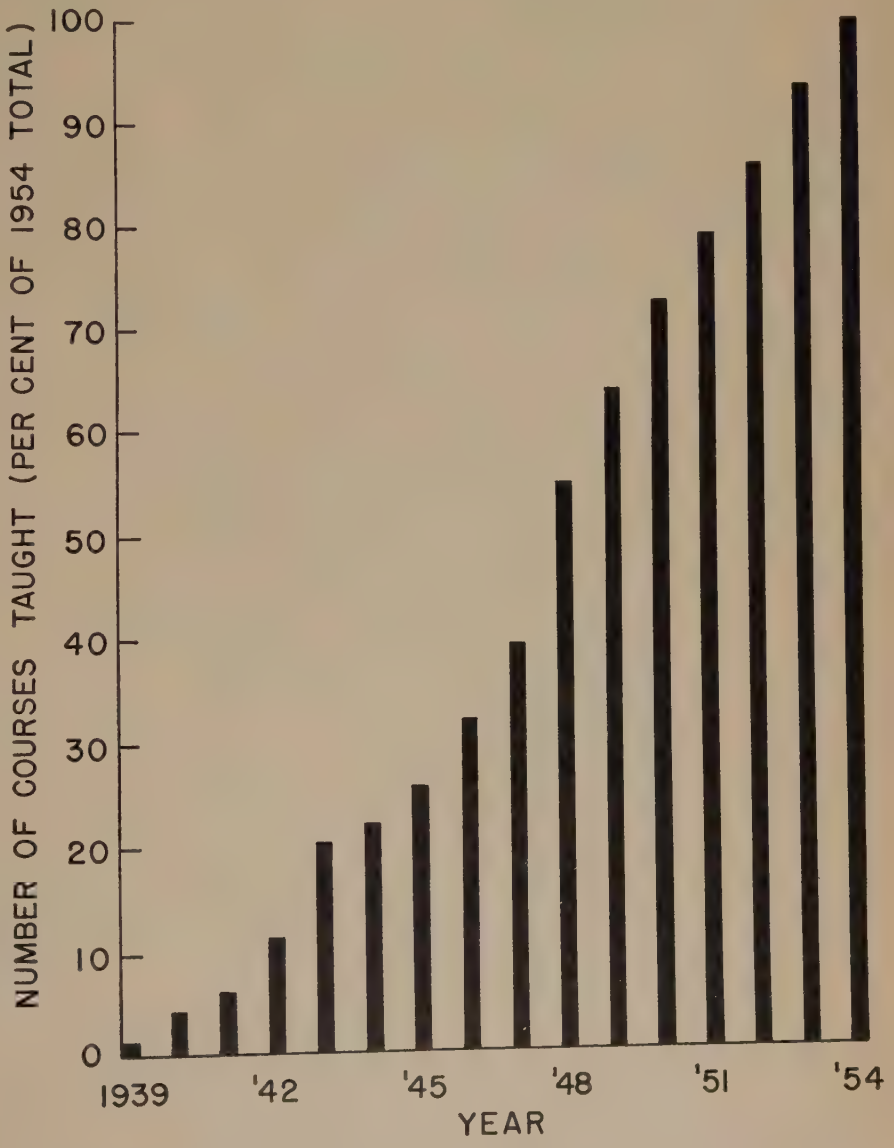

Figure 1 — Total number of courses in microwave engineering taught at Group I and II institutions, with 1954-55 as 100 per cent.

which of these (or any other) books are prescribed or used as references at each school. The same three standard textbooks[5] are most frequently prescribed at schools in both Group I and II, but the more advanced works, such as Montgomery's *Principles of Microwave Circuits* and Slater's *Microwave Electronics,* are more frequently prescribed *or* recommended in Group I institutions.

Sponsored Research

It is difficult to estimate the influence of the presence of sponsored research on the degree of specialization and vice versa. It may be safely said that the two go together, but it is not always clear which came first. Whatever the sequence, all ten institutions in Group I have relatively large microwave research programs supported by contracts and grants from the federal government; at several of the ten, large, fully staffed laboratories and other facilities have sprung up for this purpose that have only the most tenuous connection with the EE department. The inescapable conclusion seems to be that a high degree of specialization can be sustained, in the face of "competition" (for engineering talent and contracts) with other educational institutions, and of other economic factors, only by financial support from the federal government. This situation is doubtless deplored by many educators, and not always from "sour grapes" considerations alone: not a few faculty members of large and wealthy colleges would wholeheartedly agree with the conclusion of a recently published American Council on Education report[6] that "federal support of [sponsored] research . . . is not now essential to the survival of higher education in this country and should not be permitted to become so." Nevertheless, the correlation between government sponsorship and predominance in a given subject is fairly clear — and probably likely to remain the same as long as federal support continues to be distributed in the present manner.

From the viewpoint of the sponsor — in the present instance, mainly the Department of Defense — the policy of concentrating support in the institutions best equipped to use it is probably the most efficient way of getting research done. It is perhaps less obvious that this might also be the most efficient policy even if the various government agencies had no other aim than to subsidize engineering education in all institutions, large and small. If this were indeed the *raison d'être* of the government-sponsored research program, its administrators could do much worse than to encourage each school to specialize in one or two or more topics, depending on its size, rather than to try to carry out an inordinate number of highly specialized projects.

At any rate, the results of the present survey seem to indicate that a college anxious to obtain government research funds will have a better chance of obtaining them if it does specialize — a conclusion that is borne out by several well-known instances (in other fields) in which a small college without a nationwide reputation has been "put on the map" by a small, determined group of faculty members who solicited outside support on the strength of their interest in a particular subject.

Rate of Adoption

Replies to the questionnaires did not yield reliable information as to which school in America was the first to schedule a formal course devoted to ultra-high frequencies, particularly since not all of the reporting institutions were in a position to state when each course was first given. The subject was doubtless taught as part of other courses very soon after oscillators in this frequency range first became available, in the late 'thirties. The first date to appear in the questionnaires is 1939, several years before microwave engineering could have been said to constitute a significant part of the technology. The most reliable measure of the rate at which the various institutions have been adopting microwave engineering as a separate subject since then may be obtained by tabulating the total (aggregate) number of courses taught in any given year. This information, based on starting dates for over 100 courses now being taught at Group I and II schools, is plotted in Fig. 1, normalized to 1954-55 as 100 per cent.

It can be seen that adoption got off to a slow start, probably owing to military restrictions on the subject during the war years of 1939-45, when most new work in it was being done at special industrial or government-sponsored laboratories rather than in engineering colleges. Since then, the total number of courses being given has been climbing at a steady rate, and shows no sign of leveling off even after 10 years. A further breakdown shows no significant difference in the rate of adoption between institutions in Groups I and II, although this finding cannot be considered to be wholly conclusive because of the small size of Group I (10 institutions).

One conclusion is incontrovertible, however: our engineering colleges are very much alive to the challenge of a changing technology. A new topic, such as microwave engineering, has every chance of being included in the curriculum as fast as the demand arises. In fact, the results of the present survey indicate that engineering schools sometimes anticipate the demand and actually provide instruction in a new field even before it has had time to develop technologically, thus fulfilling their exalted function of leading in the progress of our civilization, rather than merely following the lead of others.

NOTES AND REFERENCES

1. This article appeared in slightly different form in the *Journal of Engineering Education.*

2. G. R. Arthur and C. Süsskind, "Report on Graduate Curricula," *Proc. Inst. Rad. Eng.* 41: 1700-1 (1953).

3. *Brooklyn Poly, California, Illinois Tech, Illinois, M.I.T., Michigan, Northwestern, Ohio State, Stanford, and Yale.*

4. *Akron, Alabama Poly, Arizona, Arkansas, Brown, Buffalo, C.C.N.Y., Caltech, Cal Poly, Cincinnati, Clarkson Tech, Colorado A. & M., Connecticut, Cornell, Dayton, Delaware, Drexel Tech, Fenn, Florida, Harvard, Iowa State, Iowa, Johns Hopkins, Kansas, Kentucky, Lafayette, Louisiana State, Loyola (L.A.), Maryland, Michigan M. & T., Michigan State, Milwaukee, Minnesota, Mississippi State, Missouri Mines, Missouri, Montana, New Mexico A. & M., New Mexico, Newark, North Dakota, Northeastern, Notre Dame, Ohio U., Oklahoma A. & M., Oklahoma, Pennsylvania Mil. Coll., Penn State, Princeton, Rensselaer, Seattle, U.S.C., Texas A. & M., Toledo, Tufts, Utah State, Utah, Villanova, Virginia Poly, Virginia, Washington, and Wisconsin.*

5. Brownwell and Beam, *Theory and Application of Microwaves;* Ramo and Whinnery, *Fields and Waves in Modern Radio;* and Reich, Krauss, Ordung, and Skalnik, *Microwave Theory and Techniques.*

6. *Sponsored Research Policy of Colleges and Universities,* Report of the Committee on Institutional Research Policy, American Council on Education, Washington, D.C., 1954.

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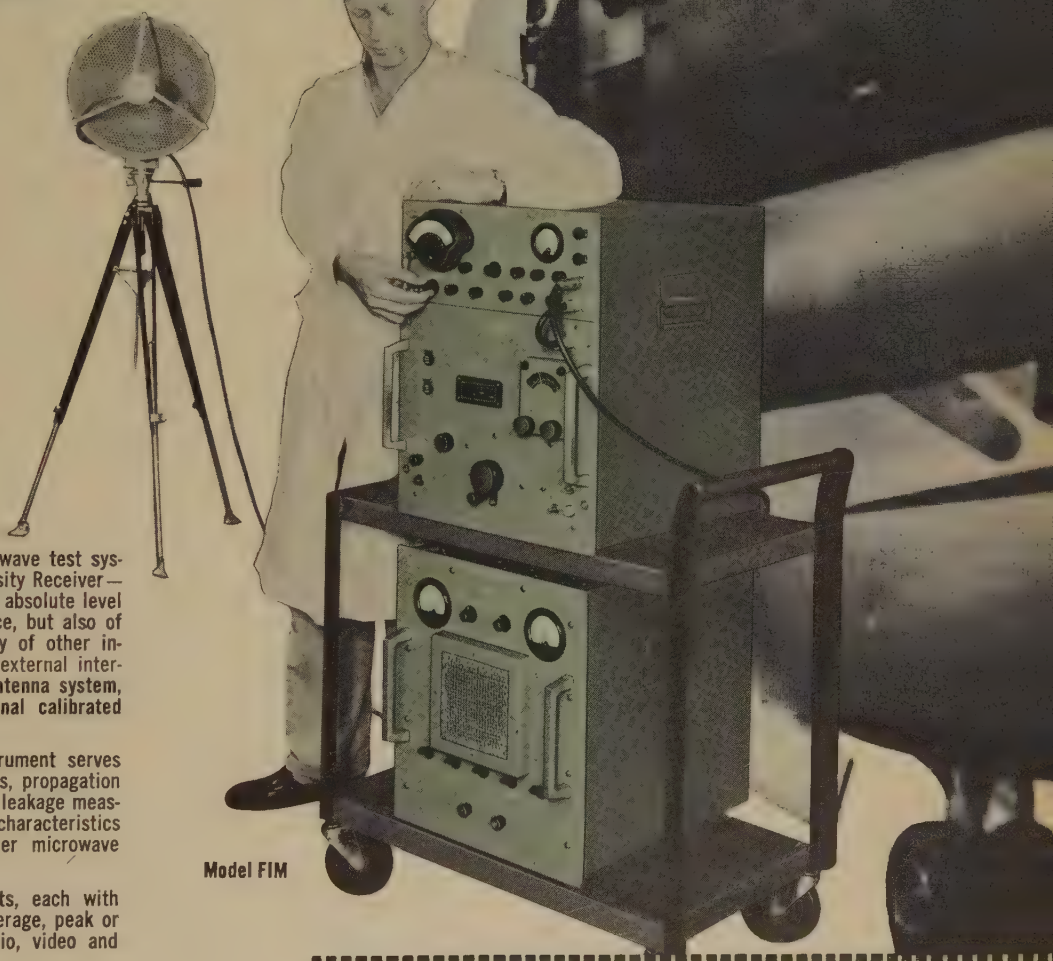

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For the first time, one single microwave test system—Polarad Model FIM Field Intensity Receiver—is capable not only of measuring the absolute level of radiated or conducted interference, but also of determining the signal susceptibility of other instruments and components to such external interference. It combines a **calibrated antenna system,** a **calibrated receiver** and an **internal calibrated signal generator.**

This versatile precision test instrument serves also for field intensity measurements, propagation studies, antenna pattern analysis, r-f leakage measurements, analysis of r-f signals—and characteristics of transmitters, receivers, and other microwave components.

Four sensitive plug-in tuning units, each with UNI-DIAL control. Meter indicates average, peak or quasi-peak value of r-f signals. Audio, video and recorder outputs.

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MAIL THIS CARD
for detailed specifications. Ask your nearest Polarad representative (in the Yellow Pages) for a copy of "Notes on Microwave Measurements"

POLARAD ELECTRONICS CORPORATION
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POLARAD ELECTRONICS CORPORATION:

Please send me information and specifications on:

- ☐ Model FIM Calibrated Field Intensity Receiver
- ☐ Model K-200 Microwave Tube Tester*
- ☐ Model P-3 Transistorized Power Meter*

MJ

My application is:_____

Name_____

Title_____ Dept._____

Company_____

Address_____

City_____ Zone_____ State_____

*See reverse side of this page.

PORTABLE TRANSISTORIZED MICROWAVE POWER METER

- 10 to 39,000 mc
- Battery or line operated
- Light and rugged
- Measures absolute r-f power instantly without tuning

Used for: field or laboratory measurement of absolute r-f power levels; testing and calibration of signal generators, attenuators, traveling wave tubes; testing coax and waveguide systems; measurement of power at locations where AC power lines are not available.

Thermistor elements make the unit safe from accidental overload. Thermistor mounts available in coaxial and waveguide sizes.

Model P-3

MICROWAVE TUBE TESTER

Simplified Test Saves Engineering Man Hours

No guesswork. No need to fire up complete equipments to determine microwave tube performance. Model K-200 gives rapid, positive decision on costly microwave tubes. Quickly pays for itself by enabling you to reclaim questionable tubes from salvage. Allows Incoming Inspection to check tubes upon receipt and throughout warranty period, without tying up expensive personnel.

Tests all microwave tubes including internal and external cavity types, pencil triodes, rocket and lighthouse tubes. A scroll indicates quick setups to test for filament continuity, short circuits, static d-c tests, life tests, and dynamic tests.

Model K-200

Postage Will be Paid by Addressee

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Persons . . . . . Places

NEW DIRECTOR OF ENGINEERING

MENLO PARK, Calif. — Dr. Sidey Frankel has been appointed director of engineering of Sierra Electronic Corporation, a subsidiary of Philco Corporation. He succeeds Paul F. Byrne, who recently retired from full-time participation in the company's activities.

Dr. Frankel comes to Sierra from the Hughes Aircraft Company, where he was senior staff scientist in the firm's Airborne System Laboratory. He previously had served in administrative, engineering and research positions with Litton Industries, International Telephone and Telegraph Corporation, Eclipse Aviation Corporation, and Warner Brothers Pictures Corporation.

Dr. Frankel is an electrical engineering graduate of Rensselaer Polytechnic Institute, from which he also holds a Ph.D. degree.

Dr. Frankel is a member of Sigma Xi and a fellow of the Institute of Radio Engineers. He has authored articles for several technical journals and is the recipient of 13 patents in various electronic fields.

• • •

CHANGES ANNOUNCED IN PHILCO'S GOV'T AND INDUSTRIAL DIVISION

Philadelphia — Expansion and reorganization of the government sales department of Philco Corporation's Government and Industrial Division was announced today by Frank D. Langstroth, Marketing Manager-Government Products.

Newly appointed product managers who will report directly to John K. Campbell, Government Sales Manager, are: A. J. Vick, Military Communications; Jerry Spiegel, Missiles; A. T. Pollock, Communications Systems, and Gordon E. Frederick, Advanced Techniques.

Mr. Vick has been with Philco since 1946, first as a field engineer with the TechRep Division and later as a microwave systems engineer with the G and I Division. More recently he was a special representative in the Washington, D.C. sales office.

Since joining Philco's G and I Division in 1952, as a sales engineer, Mr. Spiegel has served as sales coordinator on the Sidewinder missile program and as Chief Sales Engineer-Missiles. Prior to his Philco employment he was an electronics engineer with the U.S. Navy's Bureau of Ships, Washington.

From 1946-52 Mr. Pollock was with the TechRep Division as Manager of the North Atlantic and European areas, Personnel Manager and Operations Manager. He joined the G and I Division in 1952 as Manager of Field Engineering. He also worked for Philco from 1927-38.

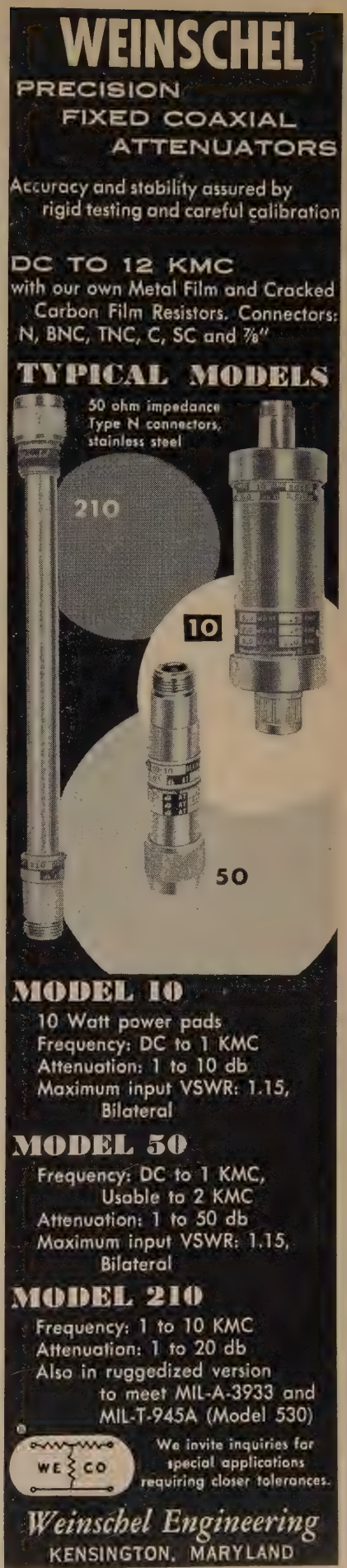
Mr. Frederick started with the G and I Division in 1952 as a regional sales engineer, Washington office. Prior to his promotion he was Manager of Sales Research and Development for Transac data processing systems.

• • •

NEREM GROWING

Speaking at a luncheon meeting held in conjunction with 1958-NEREM, the NORTH-EAST ELECTRONIC RESEARCH AND ENGINEERING MEETING, Mr. D. G. Fink, President of the Institute of Radio Engineers, commented that NEREM is the fastest growing electronics meeting.

The statistics of the 1958-NEREM are: registration 6100, technical papers 43, and exhibits 207. NEREM was held November 19-20 in the Mechanics Building, Boston; under the sponsorship of the Boston, Connecticut, and Western Massachusetts sections of the Institute of Radio Engineers.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PRECISION
FIXED COAXIAL
ATTENUATORS
Accuracy and stability assured by rigid testing and careful calibration
DC TO 12 KMC
with our own Metal Film and Cracked Carbon Film Resistors. Connectors: N, BNC, TNC, C, SC and 7/8"
TYPICAL MODELS
50 ohm impedance Type N connectors, stainless steel
210
10
50
MODEL 10
10 Watt power pads
Frequency: DC to 1 KMC
Attenuation: 1 to 10 db
Maximum input VSWR: 1.15, Bilateral
MODEL 50
Frequency: DC to 1 KMC, Usable to 2 KMC
Attenuation: 1 to 50 db
Maximum input VSWR: 1.15, Bilateral
MODEL 210
Frequency: 1 to 10 KMC
Attenuation: 1 to 20 db
Also in ruggedized version to meet MIL-A-3933 and MIL-T-945A (Model 530)
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We invite inquiries for special applications requiring closer tolerances.
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TOP LEVEL ENGINEER

To help direct key engineering program in microwave field

Microwave Associates, Inc. invites qualified engineers and physicists to discuss an unusual opportunity to direct a development group involved in the control of microwave energy by gas discharges and ferrites.

The man we seek should be well-founded in microwave theory and techniques and in gas discharge or ferrite phenomena. He will be involved in the design of new duplexer circuits, tubes or ferrite devices for advanced applications.

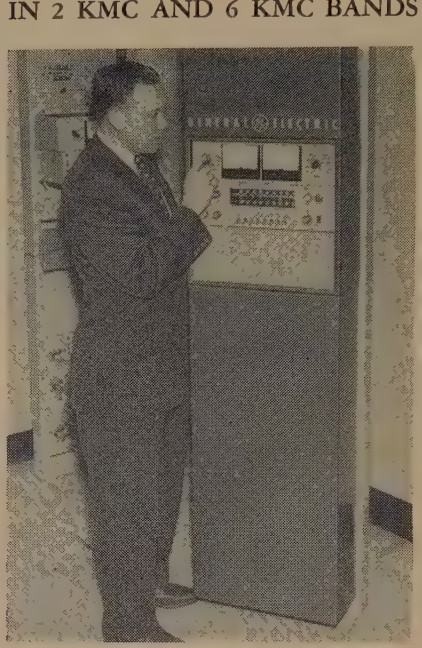
Excellent high power and low power facilities are available for complete study and test of these new devices over a wide frequency spectrum — 500 to 35,000 mc. Opportunity exists for expansion into devices using semiconductors.

Contact Dr. Jerome Kornreich for suitable arrangements.

MICROWAVE ASSOCIATES INC.
BURLINGTON, MASSACHUSETTS
Telephone: Browning 2-3000

NEW PRODUCTS

GE OFFERS MICROWAVE LINE IN 2 KMC AND 6 KMC BANDS



LYNCHBURG, VA. — General Electric's Communication Products Department here is broadening its line of Microwave products with the introduction of a new series of equipment designed to operate in the 6 KMC band. Addition of the 6 KMC line to the existing 2 KMC line places General Electric in a position to offer the communication industry the first and only microwave line operating in both frequency bands.

Announcing the availability of the 6 KMC series, General Electric's national microwave sales manager, Walter E. Sutter, said the new equipment will project the company into several new markets and will offer customers in presently served markets a wider selection of equipment to satisfy their needs.

New Systems Concept

"For the first time," Sutter pointed out, "microwave users can combine the advantages of 2 KMC and 6 KMC equipment in their systems planning. This concept makes possible greater flexibility than previously was attainable and enables system planners to achieve optimum results with a wider choice of products."

Designed with ease of maintenance as a prime objective, the new 6 KMC equipment has been engineered so that servicing concepts are close to those prevailing in the two-way radio field.

Sutter explained that the continued growth in the use of microwave dictated the need for a high channel capacity system to round out the General Electric Company's product line. The new 6 KMC line offers 120 channels to serve the expanding communication needs of microwave users.

General Electric will now offer both Time Division and Frequency Division multiplexing with its 6 KMC products and will continue to supply Time Division with its 2 KMC equipment.

CIRCLE READER SERVICE CARD 101

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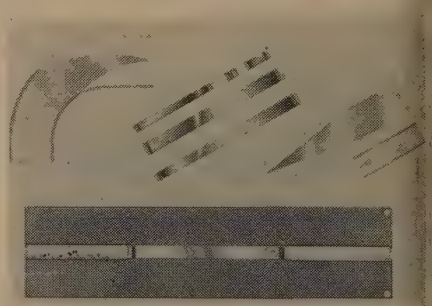
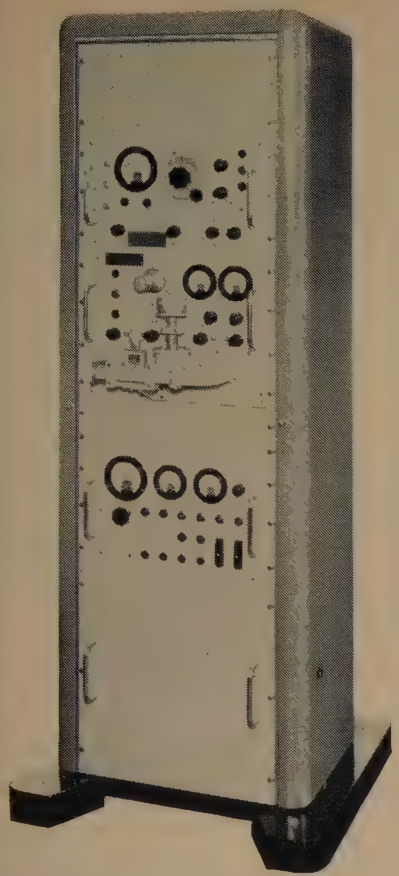
MICROSTRIP — STRIPLINE RESISTORS



FILMOHM STRIPLINE RESISTORS are a new concept in a two dimensional strip resistor. The base is a thin film of specially selected natural mica. The resistance film is an alloy of pure metals, approximately 50 millionths of an inch thick and sealed with a micro-thin coating of Quartz. Fired silver terminations can be supplied for D.C. connection of the resistor to the copper center conductor of the Microstrip or Stripline circuit.

The mica base is made as thick as the height of the copper conductor, that is, 2 mil mica for 1.8 mil copper and 3 mil mica for 2.8 mil copper. Width is equal to the width of the copper and length is determined by requirements of electrical match, power, and resistance.

A section of the Stripline is etched out and the resistor is placed on the plastic dielectric between the copper conductors. Electrical contact is made by using conductive silver epoxy cement to join the silver tab on the resistor to the copper strip. Adhesive varnish is then applied over the resistor and contact areas.



NOISE MEASURING EQUIPMENT TYPE 123

Essentially a narrow-band R.F. Spectrum Analyser, Noise Measuring Equipment Type 123 may be used for determining the spectra of spurious a.m. and f.m. modulations at frequencies close to carrier. The instrument is particularly suitable for analytical work on the performance of oscillators and systems developed for c.w. doppler radar applications.

Operating Frequency: Full sensitivity may be achieved over a bandwidth ±5% relative to carrier. The equipment illustrated is fitted with an X-band R.F. head.

Spectrum Analyser range: From 1-90 Kc/s with respect to carrier.

Resolution: 70 c/s or 1 Kc/s bandwidth.

Sensitivity: The r.m.s. a.m. sideband power in a 70 c/s bandwidth can be measured down to —135 db with respect to the total signal power level, with an accuracy of ±2 db and an equivalent accuracy is obtainable in f.m. sideband power measurements down to 0.01 c/s deviation.

Display: Panoramic display, with frequency marker, or alternatively a hot-wire instrument provides accurate power measurements when used with a manually controlled sweep oscillator.

Write for information, quoting frequency bands of interest, to:—

JAMES SCOTT & CO. (Electrical Engineers) LTD.

Manufacturing & Electronics Division

Carntyne Industrial Estate • Glasgow, Scotland

CIRCLE READER SERVICE CARD 13

The resistors can be supplied as matched loads, Fixed Pads, Variable Attenuator Elements, and Terminations. Resistance values of a few ohms to several hundred ohms can be supplied. Stripline Resistors are available as straight rectangular or square sections, tapered rectangular sections for electrical match, or curved.

CIRCLE READER SERVICE CARD 102

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VARIABLE PULSER DESCRIBED IN TECHNICAL BULLETIN

A new two-page technical bulletin describing the operation of the Model 1010 Variable Pulser, an instrument for converting any type signal source with a repetition rate up to 5 megacycles into standardized pulses of controlled amplitude and duration, has just been published by Technitrol Engineering Company.

Briefly, the bulletin covers the operating principles of the Variable Pulser describing the operation of a modified Schmitt-trigger circuit, a high-speed flip-flop and a variable delay network. The bulletin also suggests possible uses of the Pulser, for instance, for testing components and networks under pulse conditions, as a constant high frequency source or "clock" in experimental computer systems or in checking pulse circuits for response and P.R.F. sensitivity. Complete electrical and physical specifications are given along with the price of the uit. Free copies of Bulletin 1010 are available upon request.

CIRCLE READER SERVICE CARD 103

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SWEEP AND SIGNAL GENERATOR DESCRIBED IN NEW TELONIC BULLETIN

An extremely accurate and versatile new Sweep and Signal Generator for tests of IF and RF components is described in Technical Bulletin T-206 released by Telonic Industries, Inc., Beech Grove, Indiana. The bulletin gives detailed specifications of the Model SSX-2, which offers a complete marker system in a single instrument package, with provisions for obtaining audio-and-pulse-modulated CW.

According to the manufacture, the unit covers the entire low RF and common IF frequencies and simplifies testing of amplifiers and other low frequency devices by combining functions of sweep generator, signal generator, pulsed CW, and marker generator into one compact, precision instrument.

CIRCLE READER SERVICE CARD 104

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RAYTHEON CONSOLIDATED DATA BOOKLET

Compiled as a Raytheon service to the field, new Consolidated Data Booklet contains comprehensive information about principal unclassified magnetrons, klystrons, backward wave oscillators and special purpose tubes manufactured by Raytheon. Characteristics presented include maximum ratings, typical operating values, band or frequency ranges and other essential data for microwave engineers and purchasing departments.

CIRCLE READER SERVICE CARD 105

MORE NEW PRODUCTS ON PAGE 39

Note on Making E-Plane Bends in Brass Waveguide in the Small Shop

By RICHARD F. SCHWARTZ
RESEARCH ASSOCIATE IN
ELECTRICAL ENGINEERING

and

MILES E. NELSON
SUPERVISOR
ELECTRICAL ENGINEERING
MODEL SHOP

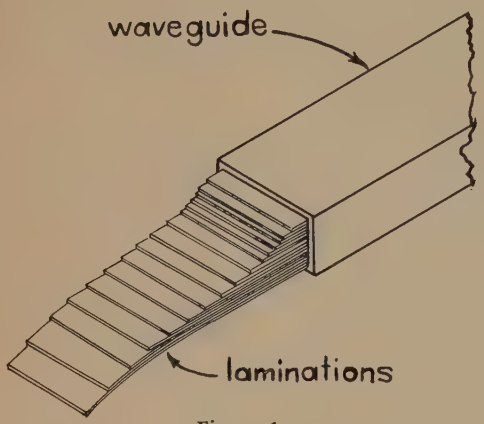


Figure 1

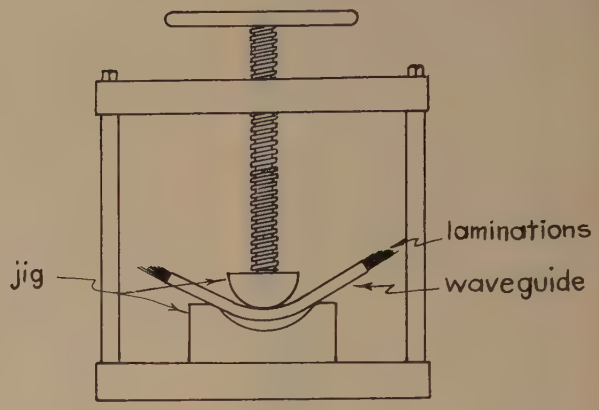


Figure 2

The problem of obtaining special sized bends in rectangular waveguide is one that frequently confronts the microwave engineer. The conventional techniques of tube bending such as filling with sand or Wood's metal are not always applicable to precision waveguide assemblies, particularly where the radius of curvature is small.

The use of thin steel laminations inserted in the waveguide as shown in Fig. 1 provides a more rigid medium in one sense, yet provides optimum flexibility for bending. During bending the sliding of the laminations on one another allows the flexibility required, and when the deformation is completed, the inserts are easily pulled out one by one.

The width of the laminations is chosen exactly the same as the inside large dimension. The thickness is chosen such that an integral number of laminations will fit into the guide when stacked one on top of the other. The remaining necessary equipment is a bending jig of the proper shape, a small hand press, and annealing facilities.

Before the process is begun the wave guide should be annealed to ensure maximum softness. After this step the guide may be expanded with a mandrel to allow the full number of laminations to be inserted and to compensate for the decrease in cross section during the bending process. The laminations are then inserted, the piece clamped in its jig, and the bend made. Finally the piece should be annealed again to remove the strains due to work hardening.

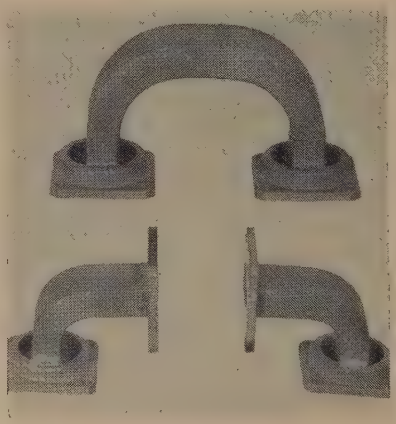


Figure 3

Figure 2 shows a sketch of the bending process taking place in a screw type press. Of course, a hydraulic or some other kind of press could be used equally well.

Figure 3 shows some typical sharp bends which were made by this process. Radii of curvature as small as 1 inch in X-band waveguide were made with this technique. While the electrical performance of such bends was not perfect, it was possible to secure some samples whose residual VSWR was 1.04 or less.

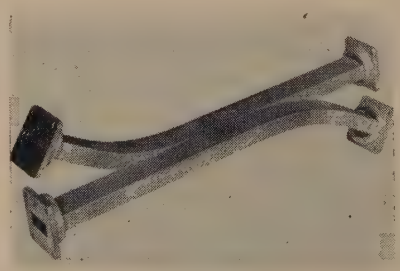
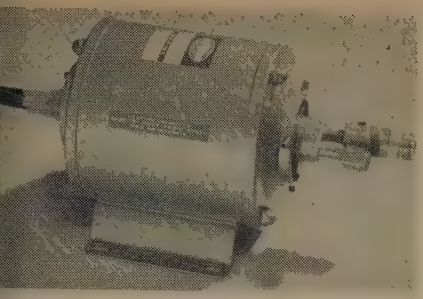


Figure 4

Figure 4 shows a directional coupler using two gradual curves obtained by the same method. Excellent test results were obtained with this piece.

Although the work reported here pertains to E-plane bends in X-band waveguide, it is likely that the technique is not restricted to this domain. For H-plane bends the laminations would have to be oriented at 90° to the position described here, i.e. parallel to the small waveguide dimension. For larger sized waveguide a more powerful press would have to be used.



RAYTHEON'S BACKWARD WAVE OSCILLATOR

Designed for voltage tunable CW or pulsed operation over the Government X-band (8500 to 9600 Mc), the QK-684 integral magnet backward wave oscillator delivers 10 to 50mw over delay-line voltages ranging from 215 to 325 vdc. Regulation of a special control grid facilitates pulsed or amplitude modulation to meet power and frequency requirements. Models available for coupling to standard, type "N" connectors.

CIRCLE READER SERVICE CARD 106

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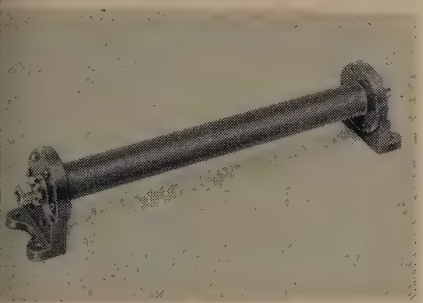
RUGGED LOW-PASS RF FILTER PROTECTS UHF — VHF COMMUNICATIONS



A new low-pass RF Filter, Model 700 with 700 Mc cut-off and rated at 300 watts C.W. is announced by Adams-Russell Company, Inc., of Cambridge, Mass. Inserted in transmission line to UHF or VHF communications antennas, Model 700 Filters will protect receivers from strong microwave interference created by nearby radars and will in turn protect radar, tacan, etc., from harmonic radiation of communication transmitters. The unit is pressure tight.

Specifications include: INSERTION LOSS: 0.3 db below 420 Mc; 60 db from 750 Mc to beyond 4000 Mc; POWER RATING: 300 watts C.W.; VSWR: 1.3 below 420 Mc in 50-ohm system; SIZE: 15 inches long by 2-½ inches in diameter.

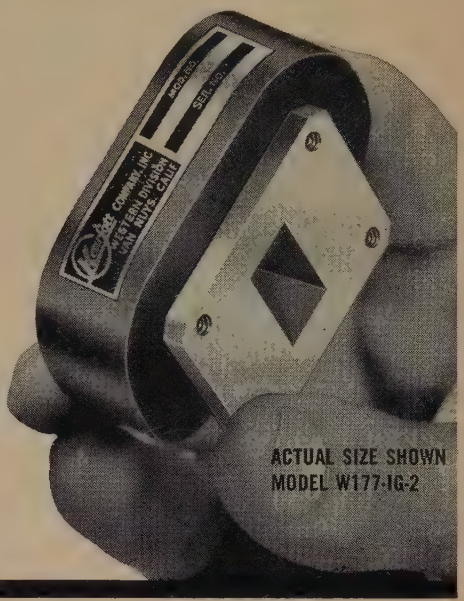
CIRCLE READER SERVICE CARD 107

REDUCE INSERTION LOSS!!
INCREASE USABLE POWER!!

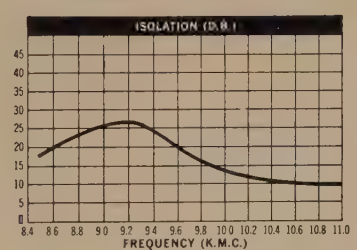
NEW

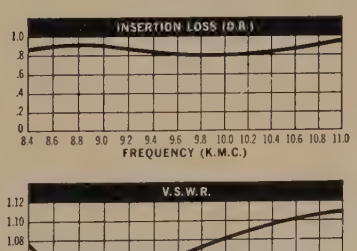
Kearfott

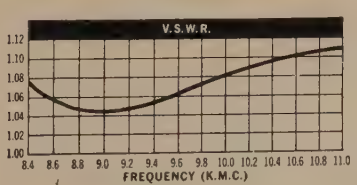
MIDGET FERRITE ISOLATOR



Typical Performance Curves







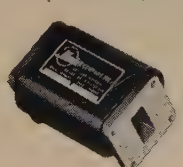
MAXIMUM FREQUENCY STABILITY WHERE SPACE IS LIMITED...

A high power unit of exceptionally small size and weight, this newest Kearfott product is the answer to microwave circuitry applications where space is limited.

IMPORTANT FEATURES:

BROAD FREQUENCY RANGE—from 8.5 to 9.6 KMC
HIGH ISOLATION—Minimum of 15 DB
INSERTION LOSS—Only 1.0 DB Maximum
SMALL SIZE—1.000" deep x 2.100" high x 2.400" high
POWER—Average 200 Watts
TEMPERATURE-AMB—150°C
PRICE—$135.00 each f.o.b., Van Nuys, Calif. Quantity prices on request
DELIVERY—from stock

OTHER STANDARD Ferrite Isolators and Duplexers in a wide range of sizes and band widths are available plus facilities to produce special configurations if desired. Our sales engineers can help you.



Kearfott

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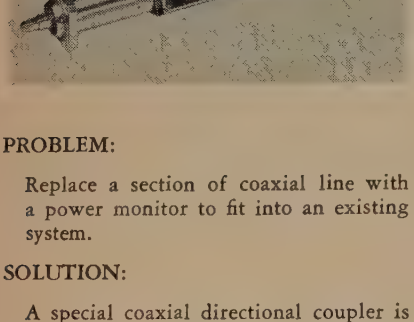
CIRCLE READER SERVICE CARD 14

CURRENT PROBLEMS

the microwave journal is interested in "current problems" that are posed to engineering groups and the solutions that have been devised. As an added service to our readers we will present at times the approaches taken to meet the customers' requirements. Was your company called to solve an unusual problem? What was your solution?
Custom engineering has become of increasing concern to components manufacturers. On this page are shown six typical problems and the way in which the Narda Microwave Corporation, of Mineola, Long Island, N.Y. has met them.

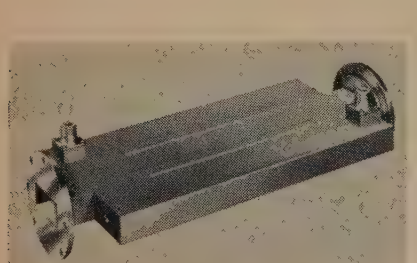


PROBLEM:

Replace a section of coaxial line with a power monitor to fit into an existing system.

SOLUTION:

A special coaxial directional coupler is designed for use with UG-45/U and UG-46/U coaxial fittings. The overall length of the primary line is controlled so that it may be used as a direct replacement of the transmission line in the existing system.



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PROBLEM:

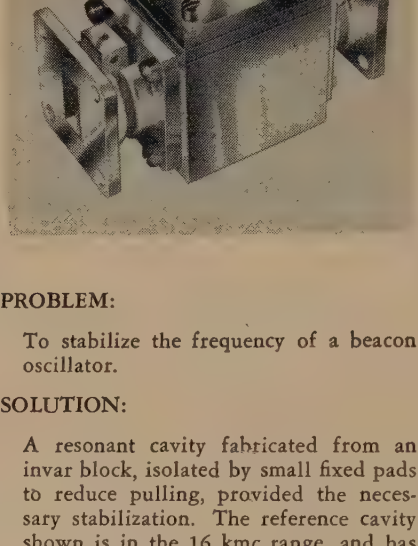
Measurement of VSWR at high power levels in limited space.

SOLUTION:

A high power dual directional coupler which samples forward and reverse power. The unit illustrated is designed to fit into the space available in the system, and has low VSWR in the coaxial outputs.

Specifications

Frequency:	5.4-5.9 kmc
Coupling, forward:	30 db
Coupling, reverse:	16 db
Directivity:	35 db
Output VSWR:	1.1 maximum
Power Rating:	500 kw



PROBLEM:

To stabilize the frequency of a beacon oscillator.

SOLUTION:

A resonant cavity fabricated from an invar block, isolated by small fixed pads to reduce pulling, provided the necessary stabilization. The reference cavity shown is in the 16 kmc range, and has a temperature coefficient to two parts per million per °C. Total insertion loss including pads is 4 to 6 db. Loaded Q is 4000.

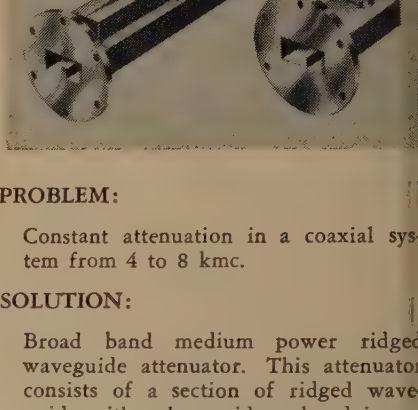
—»«—

PROBLEM:

To suppress unwanted frequencies in a fixed frequency transmission system.

SOLUTION:

A compact band pass filter which passes a fixed frequency and suppresses all frequencies below and above the fixed frequency. Such filters have been designed to operate at any fixed frequency from 200 to 30,000 mc.



PROBLEM:

Constant attenuation in a coaxial system from 4 to 8 kmc.

SOLUTION:

Broad band medium power ridged waveguide attenuator. This attenuator consists of a section of ridged waveguide with a lossy ridge placed in opposition to the single ridge. The attenuation for any setting between 0 and 60 db is constant over the range 4 to 8 kmc. Ridged guide to coaxial adapters are supplied on either end of the attenuator to provide connections to the coaxial system. The attenuator will dissipate up to 25 watts.

—»«—

PROBLEM:

Insert a directional coupler for power sampling in a crowded portion of a missile.

SOLUTION:

A teflon dielectric stripline coupler. This coupler can cover one or more octaves with minimum coupling variation and high directivity. The unit pictured has Type N fittings on the primary line and TNC on the secondary output line.

RAYTHEON MISSILE SYSTEMS DIVISION
ADVANCED DEVELOPMENT DEPARTMENT

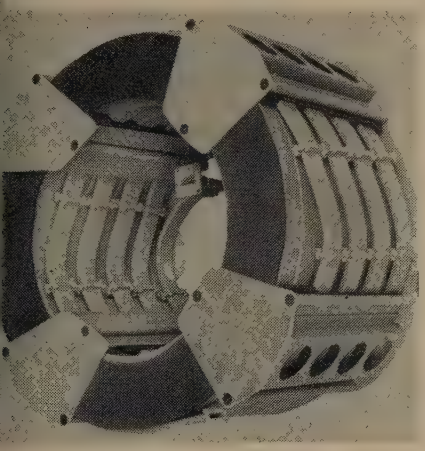
Already the only electronics company with two prime missile contracts, Raytheon now has plans for even greater expansion into missile development and production. Such continued growth and diversificati on are your assurance of job stability, individual recognition plus rapid professional growth.

Raytheon's Missile Systems Division is doing advanced development work in the expanding field of microwave solid state devices, such as microwave parametric amplifiers using crystals, ferrites, up-and-down converters, switches and harmonic generators.

All levels of positions available for those who have 2-6 years' experience in microwave component design and development. Advanced educational programs available to those who qualify.

Send resume to: W. K. Cooper, Raytheon Manufacturing Company, 520 Winter Street, Waltham, Mass., or call TWinbrook 4-0910, Extension 238 collect.

RAYTHEON MISSILE SYSTEMS DIVISION



NEW DEVELOPMENT IN SPIRAL WAVEGUIDE DELAY LINES

Cylindrical assemblies of Spiral Waveguide Delay Lines, in single coils up to 78 feet in length, and multiple interconnected systems of any length, are now being built by Turbo Machine Company, Lansdale, Pa., manufacturers and suppliers of standard and custom designed waveguide components since 1950.

Typical input VSWR measurements of these compact, light weight, and rugged units are less than 1.20 at any X-band frequency. Insertion loss is less than 0.1 db per foot of length.

The X-band delay line is constructed from 1.000" x 0.300" O.D. aluminum waveguide with brazed flanges. Manufacture is accomplished by coiling simultaneously one or more lengths of guide in the E plane on a suitable bending tool. Minimum deformation of the waveguide walls occurs, resulting in power handling capabilities near the theoretical maximum for the uncoiled waveguide.

CIRCLE READER SERVICE CARD 108

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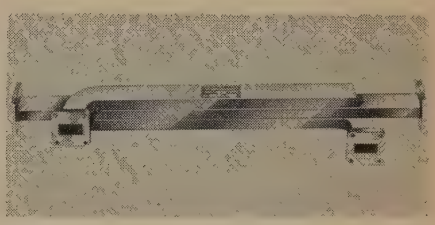
DUAL HIGH DIRECTIVITY DIRECTIONAL COUPLERS INTRODUCED BY NARDA MICROWAVE

Designed for reflectometer measurements in waveguide systems, a complete line of Dual High Directivity Directional Couplers has been developed by the Narda Microwave Corporation, Mineola, L. I., New York.

The new units exhibit the same flat coupling response (± 0.4 db) and high directivity (40 db min.) as single Narda high directivity coupler units.

Coupling structures are placed on opposite broad walls of the primary line. For maximum convenience, the



output arm of each of the secondary lines is an H-plane bend, brought out on a common side. As a result, detector mounts can be readily attached to these arms for power monitoring or for measurement of reflection coefficients within systems.

All models, with the exception of M band, are constructed from precision waveguides; milled blocks of tellurium copper are used in the fabrication of the unit covering 50.0-75.0 kmc. Coupling holes are placed on thin metallic foils which form the common broad walls between the primary and secondary lines.

Input and output arms of all models are terminated with standard cover flanges. The coupling value of all units is 20 db; primary line VSWR is 1.05 max. (1.10 for M band); secondary line VSWR is 1.15 max.

CIRCLE READER SERVICE CARD 109

WE WHO ARE preoccupied with the microwave industry are surrounded by evidence of its flourishing condition. As we relax over the Sunday papers, we cannot fail to be struck by the increasing numbers of pages of employment ads for microwave engineers. As we take the family out for a Sunday drive along most any highway, if we dare take our eyes off the car ahead, we must note the clusters of buildings comprising so-called "industrial parks," and observe that microwave firms form a relatively large percentage of these groups. We must conclude that since emergence from the laboratory such a short time ago, microwaves has rapidly become a big business, and in common with all business competition has become a force that each firm must reckon with in its own way. Signs of the times have been amply available — mergers, stock issues, expansion by borrowing, in order to prevent watering down of equity. We present these company profiles to indicate how representative companies in the microwave industry meet problems that the realities of modern business deal out to them. We hope that each will prove of interest and value to our readers; and we welcome comment and suggestions.

COMPANY PROFILE

MICROWAVE ASSOCIATES, Inc.

BOX SCORE

NAME: Microwave Associates, Inc.
LOCATION: Middlesex Turnpike, Burlington, Mass.
PRODUCTS: Magnetrons, silicon diodes, duplexer tubes, varactors, waveguide components, etc.
HIGHLIGHTS: Strongly R & D oriented, this firm is prepared to meet ever increasing demands for new, improved microwave products.

Left to Right: Richard Walker, Vice-President Engineering; George Kariotis, Vice-President Sales; Vess Chigas, Executive Vice President, and Dana Atchley, President.

Microwave Associates, Inc., of Burlington, Mass., is a company whose directors say that "in this competitive electronics industry, a growth company must offer specific capabilities to succeed." These capabilities must include, not only engineering skills, but also aggressive management and sound business judgment.

The firm was started in 1950 by three engineers, two of whom, Vess Chigas and Richard Walker are today Executive Vice-President and Engineering Vice-President, respectively. They rented 2800 square feet of floor space on Columbus Avenue in Boston, Mass., and their plan was to do microwave consulting, research and development work, and to establish a line of millimeter wave components for the swelling microwave industry.

In the first year the company did R&D work for the Signal Corps, including some pioneering in circular waveguide elements, as well as design and development of special items for industry. Encouraged by these early operations, the young company decided to enter the electron tube field, and was successful in receiving the award of an Industrial Preparedness Study contract from the Signal Corps for two magnetron types.

Meeting this contract required additional capital which was supplied out of the pockets of the founders and from a few key personnel who joined the firm and were given an opportunity to invest in the company.

Soft soldering cooling tubes on an S-Band isolator

Having entered the magnetron field, the company de-ded also to produce duplexer tubes, and expanded to w quarters of about 6000 sq. ft. in 1951. As the young mpany worked on establishing their electron tube pro-cing facilities and on the Signal Corps contract, they ccessfully bid on additional R&D work and received ntracts for waveguide components, magnetrons, duplexer bes and semiconductors. Here, then, was a turning point be faced by the management; which way to go to obtain e additional facilities and people to meet these new con-ct requirements? Vess Chigas arranged for a $100,000 an from a Boston Bank; but about this time Chigas and Valker met with Dana Atchley, then Technical Co-dinator for ABC-Paramount Theatres, Inc. They had own each other professionally earlier; and Atchley be-me convinced of the potential of the young company. He terested ABC-Paramount in Microwave Associates, and in 52, ABC-Paramount invested in the firm, buying up 0% of newly-issued shares, and Atchley joined Micro-ve Associates, Inc., as President of the Corporation.

The company was now located on Cummington St. in oston, and with the growing demands for space kept ding square feet in this plant; 6000 ft. in 1952 for R&D nctions, then again late in 1952, more space to accom-odate the demand resulting from their decision to enter e microwave diode line. By 1955 Microwave Associates d expanded along Cummington Street in five buildings cupying about 20,000 square feet.

At about this time, the Western Union Telegraph Com-ny became interested in the firm and in the significance its products and potential contribution to future com-unications techniques. They entered the Microwave As-ciates picture with strong financial backing, purchasing ares such that ownership now rested on an equal basis tween ABC-Paramount, Western Union, and manage-ent.

A new building, located along route 128, known sometimes as "Electronics Highway" was next in the expansion program, and in 1957 the company moved to this new location. This plant provides Microwave Associates with 50,000 sq. ft. of operating space; and as this is being written, a new wing is being constructed, which will add another 18,000 sq. ft., and which will house completely the enlarged semiconductor operations, including both R&D and production functions. With an eye to the future, there is ample land for further growth.

The rate of growth, at a glance, amounts to this: between 1951 and the present, the number of employees rose from 13 to 360. In its first full year of operation, Microwave Associates did $80,000 worth of business. At present, it is passing the rate of $5 million per year.

Organization

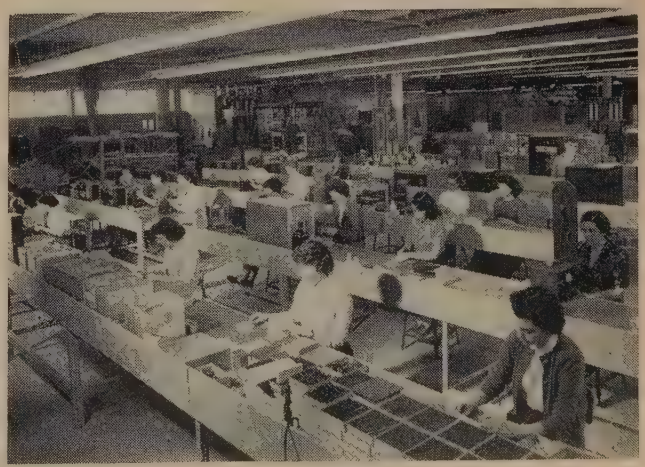
Reasons that the company advances for its success are not primarily modern technical facilities or strong financial backing. Both are, obviously, important; but also important are the presence of authority where it is required and the ability to move and execute its programs rapidly.

President Dana Atchley does not allow himself to be tied to day to day operations, but remains free to plan and develop future areas of endeavor.

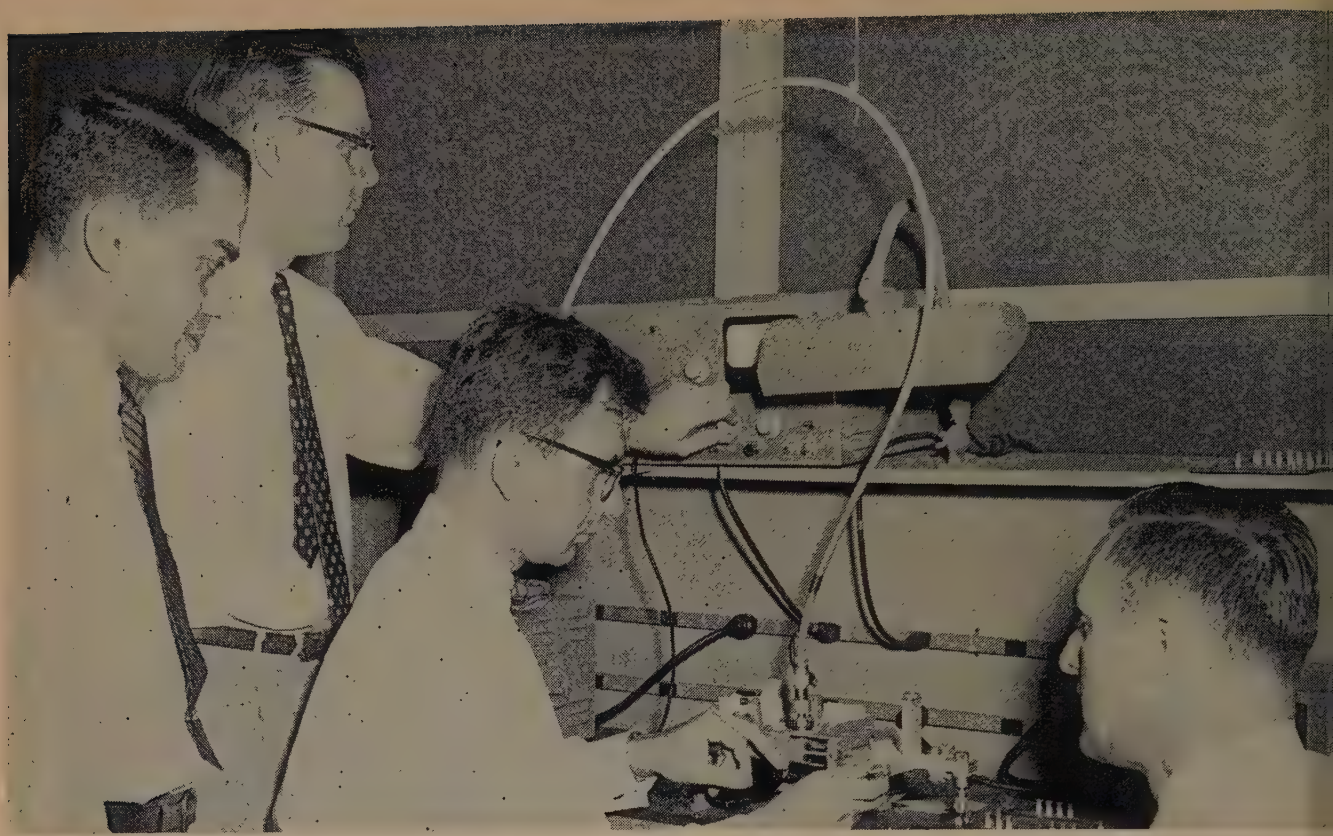
Chief executive officer, Vess Chigas, as Executive Vice President, does not like to "dilute expert talents" and believes in delegating authority as liberally as possible. This, he says, gives better incentive at all levels, and equally important, translates into efficiency.

Heading the sales force is Vice-President George Kariotis, who operates at a busy pace from both the home office and on the road to co-ordinate the company's efforts with those of seventeen sales representatives throughout the U.S. Having no company field salesmen, he and his sales engineer often service key accounts on a personal basis in order to effect the closest liaison between customer, problem, and home office engineering.

Joseph Bothwell, Vice-President for Finance has helped to maintain a firm financial position with the fluidity necessary to allow the firm to operate with competitive freedom. The proper investment of funds in proper areas at the right time has been a key factor in the company's development.



General assembly and inspection area.

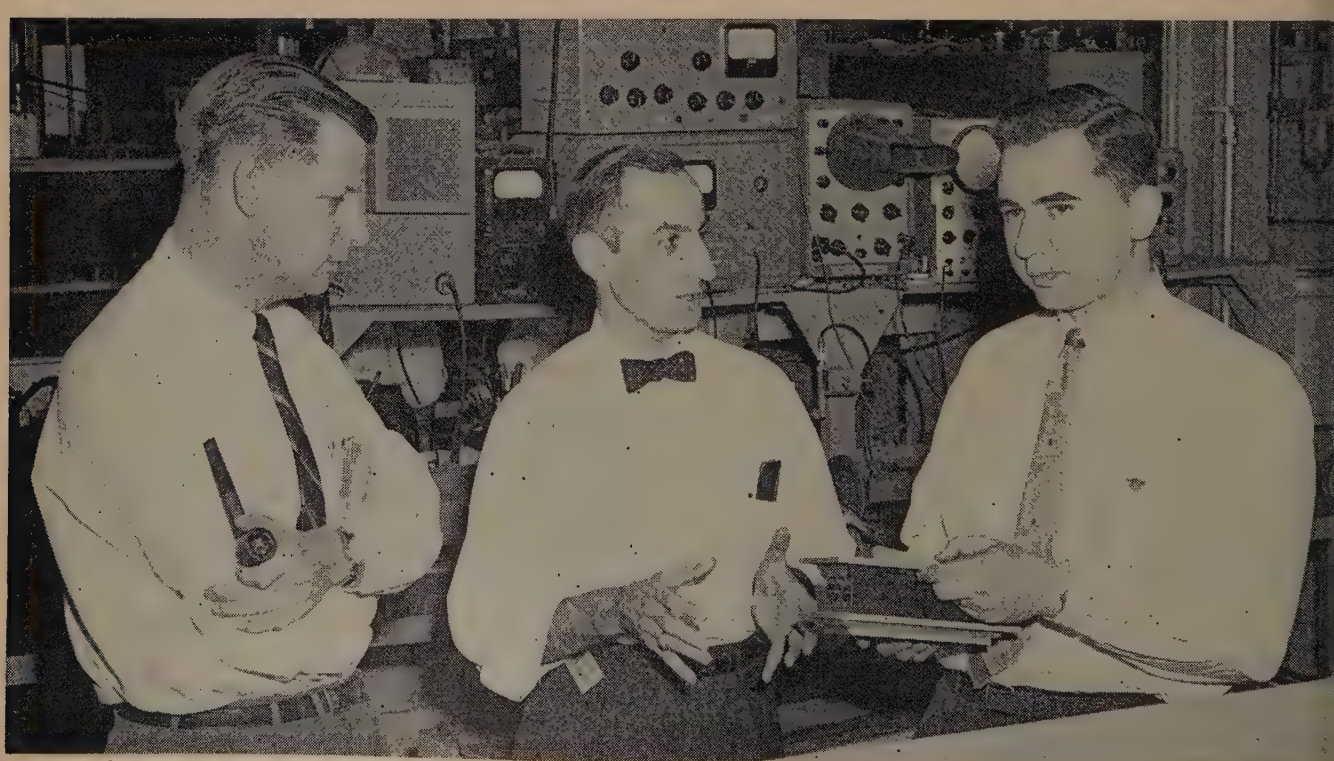


Left to Right: Howard Ellowitz, Jim Galbraith, Dr. Arthur Uhlir and Gene Deschene at Varactor Test Setup.

Basic to the expansion of any company is a continuing supply of top-notch technically trained personnel. Dr. Jerome Kornreich notes a good supply of such people in New England. He also notes that whether electronic firms are in the same product line competition or not, they co pete with one another for the same technical help.

Engineering Vice-President Richard Walker heads the electron tube and waveguide component Section; Vice President Julian Pathe is in charge of R & D for power tubes, while Dr. Lawrence Gould leads R & D for duplexe tubes and ferrite devices.

Steve Stavro, as production manager for tubes, co-ordi nates efforts in magnetron and duplexer production en gineering and production. With the co-operation of Jo Rousseau, Carl Burkart, Ken Conway and Bill Stanney the production group has made significant strides in th past year in modernizing machinery and methods, and i increasing output.



Vice-President Julian Pathe, Left, and Dr. Lawrence Gould, Right, consider statements of tube production manager Steve Stavro, cent

Microwave Associates, Inc. main building — new wing rising at the left.

Newly appointed manager of semiconductor operations Jim Galbraith.

Dr. Arthur Uhlir,* formerly of Bell Labs., heads the rong semi-conductor Research and Development Sec- on, and Gene Deschene puts his talents to good ad- ntage in supervising all production.

Typical key personnel rounding out the management am are Norman Houlding, Sam Harris, Howard Ello- itz, Dan Lanciani, Allen Swartz, Arthur Blaisdell, Harry erchant, Dave Jenny, Jack Spanos, Ralph Collins, Erik romsted and Bill Foster.

ompany Products and Activities

As the missile programs continue to expand, the de- ands on R&D rise logarithmically. Microwave Associates els that it has met these demands. In support of this eling, they quote assignments completed by their R&D oups, such as miniaturization of existing power tubes, sign of improved broad band pressurized waveguide indows, and the solution of numerous gas physics prob- ms.

The company points to the successful development of a riable capacitance diode (varactor) which, in conjunc- on with their specially designed parametric amplifier, creases sensitivity of existing radars by rather remarkable ctors.

Perhaps the most important of Microwave Associates' ie in terms of contribution to the industry is in the field microwave silicon diode detectors. Almost 100 differ- t types are produced, and President Dana Atchley says We feel that we have contributed substantially to im- oving microwave reception by designing and producing ore sensitive silicon diodes than were available before we tered the field."

Sales Manager George Kariotis indicates the important ntributions of the company's R&D departments in mag- tron design. These have resulted in the use of a special cathode, which increases tube life, and unique features which permit operation under tremendous shock, vibration and acceleration conditions. Recent concentration has been on further development of low and medium power Ka band tubes. A magnetron manufacturer since 1952, the company now makes nearly 50 types, adding new designs annually.

Duplexer tubes capable of handling multi-megawatt powers, specialized microwave test equipment, and an extensive array of waveguide components round out the company's product line.

Financing — Sales — Outlook

A brief mention has already been made of the financial facets of the company's history. In June of 1957 a public offering of shares in the Company was underwritten by Lehman Brothers, and the Company became publicly owned. Company employees are well represented in this ownership, with a third of them holding shares.

In one and one-half years the market value of the stock has risen from seven to about thirty dollars per share.

Presidents of ABC-Paramount, Western Union, their top technical vice-presidents, and a senior partner of Lehman Brothers join with management board members in giving close attention to all matters affecting the future of the firm.

This combination places strong importance on continuing Research and Development; this is evidenced by the following figures; company sponsored R&D programs budgets increased from $99,000 in 1956 to $300,000 in 1957, and in this year were again increased to $400,000.

Sales in 1958 were the best in the company's history, and represented a healthy 64% increase over 1957 sales.

Probably as significant a pointer to the future of Microwave Associates as any collection of facts and figures is the common reply to thet question, "What's going into the new wing?" The most heard answer at Microwave Associates is "IDEAS . . . lots of new ideas!"

ee microwave journal, sept./oct. 1958 page 17.

RADAR SYSTEMS AND COMPONENTS ENGINEERS

At Autonetics our current long-range programs and new programs require the addition to our technical staff of several unusually capable engineers having analytical, experimental, or developmental experience in radar microwave and antenna fields. Among our projects are monopulse radars for armament control and bombing navigation systems. This work ranges from basic research and analysis—leading to a choice of system parameters—to actual development of components.

The above positions are open to Engineers with B.S. engineering degrees, as well as to those who have graduate training. Salaries are competitive and open.

Investigate these exceptional opportunities by sending your resume to:

Mr. S. L. Benning, Autonetics, 9150 E. Imperial Highway, Downey, Calif.

Autonetics
A Division of
North American Aviation, Inc.

MICROWAVE ENGINEERS

If you are interested in advanced components development . . . if you would like to work with a rapidly growing group which is a leader in the field of ferrites . . . if you would like to live near Boston and its numerous universities . . . then we would like to talk with you.

We seek engineers with solid microwave experience and an educational background in physics or electrical engineering. We need both junior and senior men.

Please send your resume to

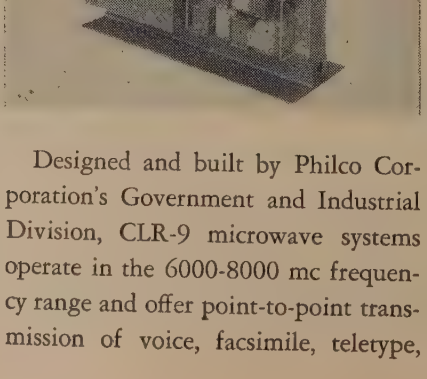
Dr. Howard Scharfman, Special Microwave Device Group
RAYTHEON MANUFACTURING COMPANY
River Building #2, Waltham 54, Massachusetts

If you are in the area and care to call we can be reached at TWinbrook 3-5860, Extension 4141.

PHILCO DESIGNS NEW MICROWAVE RELAY EQUIPMENT

PHILADELPHIA — The new Philco CLR-9 microwave relay equipment is designed to provide duplex, point-to-point transmission of a wide-band, composite signal for communications applications that require top performance and unattended reliability.

Also, special emphasis has been placed on integrated standby facilities to provide maximum operation reliability at moderate cost.



Designed and built by Philco Corporation's Government and Industrial Division, CLR-9 microwave systems operate in the 6000-8000 mc frequency range and offer point-to-point transmission of voice, facsimile, teletype, data telemetering and supervisory control information.

As many as 240 high quality, low noise voice channels may be transmitted with an unexcelled degree of performance reliability over a single CLR-9 microwave relay path for several hundred miles.

Outstanding features include the efficient utilization of special compact circuit panels, plug-in chassis, ferrite isolators, tubeless semi-conductor power supplies and front panel adjustments and controls. Also, only six different tube types are used in the CLR-9.

Blowers, normally used for dissipating klystron heat, have been replaced with more compact, trouble free, convection cooling heat sinks.

Being compatible with other Philco Microwave equipment, the CLR-9 is designed for unattended, fully-automatic operation, and can be utilized with a variety of frequency-division or time-division multiplex equipment for single, as well as multi-hop relay applications. When automatic standby equipment is desired, both primary and standby equipment are located on the same rack.

CIRCLE READER SERVICE CARD 114

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Bomac Laboratories, Inc., Beverly, Mass. has recently released a 6-page folder on their line of pressurizing windows. Included are specifications on choke flange mounted types, soldered types, special types, ceramic windows, and some miscellaneous types. Also included are outline drawings and a general discussion about windows.

CIRCLE READER SERVICE CARD 115

RUGGEDIZED MASER

Dr. Robert M. Bowie, Vice Presi-lent of Sylvania Research Laborator-es, a division of Sylvania Electric Products Inc., said the company is ngaged in a program to "rugged-ze, miniaturize, and package" the MASER, so that it may be used, ini-ially, in military applications, and ltimately in industry and peace-ime scientific research. MASER de-ices, he added, now are being ex-lored and developed "principally n the laboratory stage" by univer-ities and industrial research organi-ations.

The crystal, "heart" of a MASER levice, emits stored energy to am-lify a weak signal received by a ra-lar antenna.

The Sylvania concept of a "pack-ged" MASER system would include niniaturized cooling system and nagnet as integral parts.

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PHILCO DEVELOPS "ATOMIC" AMPLIFIER FOR SIGNAL CORPS

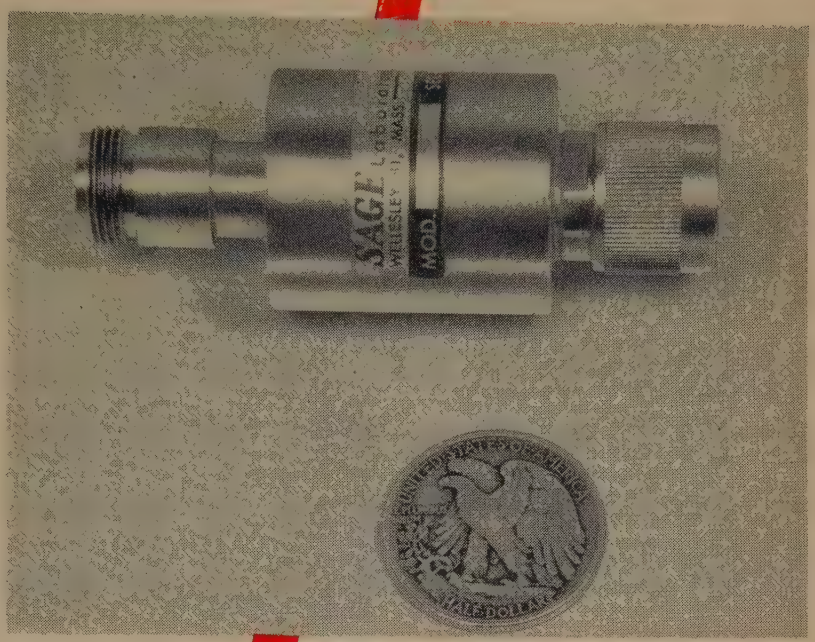
Philco Research has set a new first n the development of a special type f gas Maser, also known as an atomic" amplifier.

Allen C. Munster, Director of Re-earch for the Government and In-ustrial Division, said the Maser tudy is being conducted for the rmy Signal Engineering Labora-ory, Fort Monmouth, N. J.

The Philco Maser is the first atomic" amplifier to demonstrate nilateral (one-way) gain of micro-ave energy by means of two electri-ally isolated cavities connected by a eam of neutral ammonia gas mole-ules. Energy is transferred from ne electro-magnetically isolated oint to another by the flow of these olecules.

As the oscillating molecules pass rough the second cavity, electro-agnetic radiation is developed and appears in the output waveguide. hus is achieved unilateral amplifica-on without aid of electronic effects.

The Philco Maser also has demon-rated the predicted physical phen-menon of prestimulation of mole-ules in an excited state. Prestimula-on in a two-cavity device promises provide a greater degree of free-om for controlling the gain-band-idth properties of an "atomic" am-ifier.



SAGE

The SAGE-305 coaxial rotary joint is designed to cover the frequency range from DC to 12,400 MC. From DC to 5,000 MC the nominal VSWR does not exceed 1.1:1. From 5,000 to 12,400 MC the nominal VSWR does not exceed 1.25:1. The unit is designed for continuous duty at a maximum speed of 500 R.P.M. and intermittent duty at 1,000 R.P.M. Insertion loss is less than .1 DB. Wow is negligible.

CIRCLE READER SERVICE CARD 1

SAGE laboratories, inc.
159 LINDEN STREET WELLESLEY 81, MASS.

SYLVANIA'S AMHERST LABORATORY

has Immediate Openings in its

NEW MICROWAVE & ANTENNA SECTION

THE MICROWAVE AND ANTENNA SECTION operates as a service function to the Laboratory in the areas of microwave component and microwave system development, microwave instrumentation, standardization, antenna development and bid and proposal preparation as related to systems.

The group will undertake problems in typical applications such as radar, communication, beacon, electronic countermeasure, navigation sets, transmission systems, instrumentation techniques and gain calibration. Development will be effected on such items as horns, reflectors, antenna assemblies, arrays, linear and circularly polarized antennas, and radomes.

Qualified engineers with a BS in EE or Physics (advanced degree very desirable) and a minimum of 5 years experience are urged to inquire about the openings immediately available.

MICROWAVE COMPONENTS: There is a need for development and design engineers with experience in the areas of: directional couplers, mixers, equalizers, filters, power dividers, rotary joints, special instrumentation devices.

ANTENNAS: Engineers with experience in broadband microwave antennas are needed. The group will be responsible for all phases of antenna development and design, from initial conception through prototype.

Please write to Norman C. Gibbs

AMHERST LABORATORY • SYLVANIA ELECTRONIC SYSTEMS

SYLVANIA

SYLVANIA ELECTRIC PRODUCTS INC.

1115 Wehrle Drive — Amherst 21, New York

RAYTHEON MAGNETRON OSCILLATOR

Where abnormal conditions of vibration (25 to 2000 cps at 10G) are encountered, such as in advanced airborne applications, this pulsed-type X-band (9245 ± 40 Mc) air-cooled RK6967A/QK366A magnetron oscillator maintains exceptional frequency stability and operational reliability. Optimum performance is assured by a double-end supported cathode and aluminum-clad integral magnets. Nominal peak power output is 100 kw at typical pulse conditions of 0.5 μ sec. (.001 duty cycle). The tube operates at a peak anode voltage and current of 15 kv and 13.5 amp. respectively.

CIRCLE READER SERVICE CARD 116

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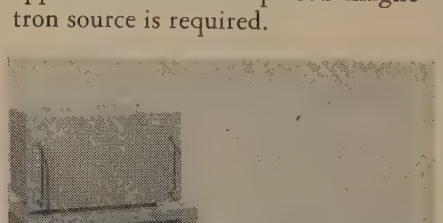
MAGNETRON R-F SUPPLIES FEATURE REMOTE TUNING

A series of tuneable Magnetron R-F Supplies from S through K_a bands are particularly suited for use on antenna pattern ranges and other applications where a pulsed magnetron source is required.



Each R-F Supply is divided into three physical units: a modulator, an r-f source, and an optional remote control unit that permits complete control from any location. The following modulator main-panel controls are duplicated on the remote unit: "Off-Standby-On" switch; low-high magnetron tuning-motor pushbuttons; magnetron frequency meter; magnetron plate-current meter; prf adjustment.

Typical specifications for the r-f sources are — X-band: type 2J51 magnetron; tuneable, 8,500 to 9,600 mc; 35 kw nominal peak power. S-band: 2J66 magnetron; tuneable 2845 to 2905 mc; 15 kw nominal peak power. Other units are tuneable where tuneable magnetrons are available.

Unless different values are requested, the modulators are supplied with a pulse rate of 1000 pps (adjustable ± 20%) and a pulse width of 1 microsecond.

The modulator and r-f source are designed for outdoor use with minimum, open-shed protection.

Manufactured by CALIFORNIA TECHNICAL INDUSTRIES division of Textron Inc., 1421 Old County Road, Belmont, California.

CIRCLE READER SERVICE CARD 11

NEW PRODUCTS

BOMAC ANNOUNCES EXTENDED TEMPERATURE RANGE TR TUBES

Bomac Laboratories, Inc., Beverly, Mass., announce a new line of extended temperature range TR tubes. These tubes are self-contained and are capable of meeting all standard electrical and mechanical specification between temperatures of —55°C to +125°C. All tubes are interchangeable with present JAN TR tubes in current use. The new extended temperature range TR tubes are available in all bands.

CIRCLE READER SERVICE CARD 118

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EMERSON-CUMING DEVELOPS NEW CASTING RESIN

Stycast TPM-4 is a casting resin curable in the range of 400°F to 500°F. It is a rigid, thermosetting plastic with electrical and physical properties equivalent to those of Eccostock HT 0003. Hexagonal steel bars have been embedded in Stycast TPM-4 and shocked from +300°F to —70°F without failure. Shrinkage during cure is very low and thermal stability is continuous at 500°F. This material represents the closest approach yet to a "castable Teflon."* The curing schedule is long and slow but simple to accomplish even when large sharp-edged objects are embedded.

Write for Technical Bulletin 7-2-A completely describing this material.

* Registered, E. I. DuPont

CIRCLE READER SERVICE CARD 119

NOVEL TELESCOPING ANTENNA MAST REVIEWED IN NEW I-T-E BULLETIN

The first practical portable telescoping antenna mast — a major advance for Army field communications — is described in a new bulletin published by Special Products Division of I-T-E Circuit Breaker Company, Philadelphia.

The four-page bulletin — fourth in a series of reports on antenna system and waveguide engineering accomplishments — describes in detail the design and performance features of the pneumatically operated telescoping microwave antenna mast, developed after 15 years of industry and government effort.

The new mast—20 feet high when first erected and capable of being automatically raised an additional 30 feet — provides performance previously unavailable in this type of equipment.

The mast provides these performance features:

Stability — holds a microwave antenna beam on direction with only a plus or minus three-quarters of a degree shift in a 60-mile wind.

Portability — can be carried in a small truck in five compact packages and then completely assembled and erected in 30 minutes.

Rapid operation — the mast telescoping section can be fully extended or retracted in only three minutes.

Mechanical lock-up — each telescoping section, upon reaching its extended position, is automatically locked in place through a positive mechanical latching system.

All-weather operation—if jammed by ice, the fully extended mast can be lowered and raised through a gin pole arrangement incorporated in the base.

Power for the mast is supplied by an electric motor-driven air compressor. Controls, all integrated into an operator's section at the base of the mast, include those for main power, mast pressure, telescoping direction, antenna elevation and antenna azimuth.

CIRCLE READER SERVIC CARD 120

Whatever your spectrum

of uses for fabricated plastic parts, DIELECTRIC PRODUCTS can work effectively with you in developing

- **Radomes**
- **Reflectors**
- **Antenna Housings**
- **Missile Fins**
- **Assembly and encapsulation of circuitry**
- **Fiberglass laminates for high temperature use**
- **Molded thermoplastic and thermosetting parts**

Our development and production facilities are available for your immediate use when you call KEystone 4-8311.

DIELECTRIC PRODUCTS

98 ADAMS STREET
LEOMINSTER, MASS.

DIVISION OF
Commonwealth Plastics Corp.

CIRCLE READER SERVICE CARD 17

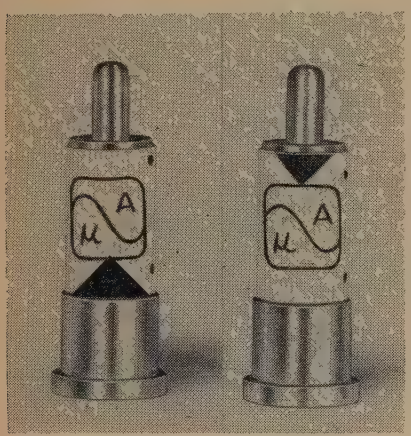
EXPANSION AT MICROWAVE ASSOCIATES

Burlington, Massachusetts

Microwave Associates, Inc., announces planned expansion of its semiconductor line as it prepares to occupy additional space being added to the present plant.

Mr. James S. Galbraith, Manager of Semi-Conductor operations, stated that work continues on power-type silicone rectifiers with new ratings and sizes being developed. In addition, he stated that in the past year Microwave Associates had expanded its microwave crystal production considerably.

Several new, low-noise crystals were developed and has found wide acceptance in the field and several new coaxial and tripolar types will be in production in a few months.



New Variable Capacitance Diode Varactors.

Current interest is most keenly focused on the variable capacitance diodes varactors and this has been proportionally higher as the capacities of the new varactors become more widely known.

Using its MA-460 varactor, Microwave has developed a parametric amplifier which has shown outstanding performance at 500 mc with noise figures of 1 decibel or less.

Pilot line production has been underway on the varactor for several months and it is planned to start varactor production in the new wing when it is completed in April. Pilot line production is now starting on the MA-1 parametric amplifier.

Research and Development efforts in 1959 will include work on the S-band and X-band parametric amplifier, solid state harmonic generators, and other promising solid state devices.

CIRCLE READER SERVICE CARD 113

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Should Your Son be a Microwave Engineer?
Should He be a Doctor, Lawyer, Indian Chief?
Does He Have Enough Information to Help Him Make This Important Decision?

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Jan. spec: Tuneable 2700-2900mc, 1.5db max. loss at ctr freq over band. Details: Insertion loss variable. Single tuned filter for freq channelling in radar beacon. Invar center tuning conductor ¾ wavelength. New $37.50 each.

AN/APS-10 RF HEAD

3 cm. 10kw output, hydrogen thyratron mod. .8 microsec. rcvr 30 mc IF 5.5 mc bandwidth. Uses 30 tubes 3xtals plus 2J42 magnetron, $375 ea. Full desc. MIT. Rad. lab. series Vol. 1 pg 616-625.

10 CM. RADAR SYSTEM

US Navy Raytheon 275 KW peak output S band. Rotating yoke Plan position Indicator. Magnetron supplied. 4, 20 and 80 mile range. 360 degree azimuth scan. Sensitive rcvr using 2K28/707B and 1N21B. Supplied brand new complete with instruction books and installation drawings. Can be supplied to operate from 32VDC or 115 volts. Price $975. Ideal for weather work. Has picked up clouds at 50 miles. Weight 488 lbs.

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3 CM. KLYSTRON MOUNT

2K25-723A/B mount with cplg. to waveguide run and afc. Shielded incl. tuning rod. Matching tuneable output slugs. Dual crystal mount. Pwr cable w/min. plug. Brand new. $28.50.

APS-31A 3cm. RF head. 100kw output using 4J52 Magnetron. Complete with balanced mixer (2K25's) miniature IF strip, compl. receiver, pressurized housing. All tubes incl. As new. $395.00.

⅞" RIGID COAX. 50 ohm, standard fittings, 10cm stub supported. 12 ft. lengths. Silver plated. New $34.50 each. RG44/U. 12 ft. length. Right angle bends $6 ea.

2C37 SYLVANIA ROCKET TUBE $17.50. Complete mixer assy cavity with FM sweeping motor 3cm harmonic. Sperry. Brand new. $35.00.

TOPWALL HYBRID JUNCTION. 8500-9600mc 1x.5 wg size. Broad banded better than 16%. Aluminum casting. $15.00 new. Crossover output, 1x.5 wg size. $5.00 new.
BROAD BAND BAL MIXER using short slot hybrid. Pound type broad band dual balanced crystal holder, 1x.5 wg size. $25.00 new.

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COAX MIXER ASSEMBLY IN21 type crystal detector RF to IF, 'N' fittings, matching Slug, duplex couplings, mfg. G.E. New, $18.50.

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AN/MPN-1A GCA SET

Ground control approach equipped trailer with 3 cm precision and 10 cm search radars plus full complement precision and search indicators. All in original trailer. Call — write for info. and price. Fully Desc. MIT Rad. Lab. Series, Vol. II, pps. 237-251.

3KW 400 CYCLE SOURCE

Complete generator set 115vdc 4HP motor (easily swapped for standard GE or other 115v 60 cycle AC motor) speed regulated. Generator output 115 volts 400 cycle single phase 17.4 amps continuous duty. Output electronically regulated. Built to rigid US Navy spec. In excellent used condition. A new special price $285.00.

PRESSURIZED WINDOW 1 x ½" guide Varian V1100 New $5.50.

SPERRY KLYSTRONS

SMX-32 Amplifier-Multiplier 9.0-10.5-KMC. Amp. freq. multiplier; output power 1.5 to 2 watts at 9000 to 10,500 mc; drive freq. 4500 to 5250 mc. New in original sealed cartons. Guaranteed 60 days. Regular price $925 ea. Our price $425 ea.

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COMPLETE RADAR PLUMBING FRONT END. c/o 2K25 local osc. mount, 2K25 beacon mount, type N adapter, crystal mount with tuning slug, variable attenuator, beacon xtal mt. beacon N adapter. Also matching duplexer assy. Latest type Navy Radar. Ideal for radar front end or as a **complete laboratory bench set up.** Price incl. duplexer $52.50. Less duplexer $42.50. Brand new electrical and mech. tested.

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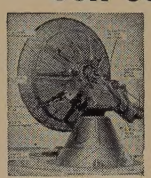
X band. Broad banded. BNC (teflon) output. UG39 Flange Input. VSWR better than 1.0 Mfg. Airtron. New. $24.50.

S band type N crystal mount. A coax line mounting for ceramic cartridge crystals (i.e. IN21, IN27, IN32 types) with tuning element for impedance matching. Standard type N connector input, ⅜" coax line. Stub supported for 10cm. Pressurized. Silver plated. Excellent as crystal mount, low level converter, beacon receivers, etc. New $15.00.

ANTENNA PEDESTAL SCR 584—MP 61B



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Complete description in McGraw-Hill Radiation Laboratory Series, Volume I, page 284 and page 209, and Volume 26, page 233.

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3cm. waveguide feed back horn, RG-52, aluminum, pressurized window. Mfg. for Western Electric by NRK. Each calib. with VSWR, etc. Brand new. $16.50.

KLYSTRON MOUNTS

3CM. Precision Tube Mount. Waveline model 688. X band shielded klystron mount PRD signal generator type. Complete with variable glass vane attenuator. Brand new. $205. list Price $64.50.
S. band. Type N output. Tuneable over entire band. For Shepard type tube i.e. 726 w/socket & tube clamp. Mfg. GE. New, $15.00.
K band. 2K50 output cplg. w/90 deg. H bend. New. $19.50.

10 CM. DUAL CHANNEL BEACON RECEIVER

Low level converter rf to dc to control amplifiers. In pressurized housing apx. 6 in. dia., 10 in. lg. Uses 1N27 crystals. **$52.50 each.** F-28/APN-19 filters for above **$37.50 each.**

DIRECTIONAL COUPLERS

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X band. RG51/U di-directional. Airtron calibrated 20db. New $22.50.
K band. 1.25 cm. 20db. CU-136UP. Standard fittings. Coin silver. New $45.00.

SPERRY MICROLINE double slug tuner for ⅞" coax Model 363. $285.00.
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ANTENNA GYRO STABILIZER. Bendix Gyro Servo Unit. Combined horizon gyro, Autosyn & tilt correction motor. Maintains tilt stabilization of radar antenna, etc. Pioneer 12800-1-B (APS-15). New $75.00. Ref: MIT Rad. Lab. Series, Vol. I, pps. 306-308.

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CIRCLE READER SERVICE CARD 18

The Outlook for Ferrite Devices

Notes of the Industry

By DICK BARLOW
MANAGER
ELECTRON TUBE INDUSTRIAL SYSTEMS DIVISION
HUGHES PRODUCTS

WHY FERRITES

Until the advent of ferrites, microwave transmission circuits were reciprocal in nature. That is, energy flowing in one direction obeyed the same rules as energy flowing in the reverse direction. Energy from a transmitter tube flowed essentially unattenuated to the antenna — but energy reflected from the antenna, and from other parts of the transmission system, likewise flowed in full force back to the transmitter, and kept it from doing its proper job. Not so if a piece of ferrite is put into the waveguide system and surrounded with a magnetic field. In this material, a blend of iron oxide with certain other metallic oxides, unpaired electrons are free to spin like a host of charged gyroscopic tops. When placed in a polarizing magnetic field, these electron "gyroscopes" combine to interact with a superimposed electromagnetic field and so to redirect or attenuate it. Now the reflected wave from the antenna no longer spoils the transmitter spectrum, shifts its frequency, or reduces its power output. By combining ferrites and magnetic field with various conventional types of microwave circuit elements, not only transmitter isolators, but many other non-reciprocal and heretofore unrealize-able microwave devices have been made possible.

WHERE FERRITES

The present uses of ferrites in electronics is quite extensive. For instance, deflection yokes for television picture tubes, automobile and portable radio antennas, magnetic switching cores for magnetic memories, permeability tuning slugs, transformer and coil cores and noise suppression filters, carrier telephone filters, H-F chokes, pulse transformers, audio transformers, delay lines, permanent magnets, ultrasonic vibrators, magnetic amplifiers, tape recorder heads, mechanical filters, ignition coils, saturable reactors, proton and elementary particle accelerators, H-F coupling devices, I-F transmission devices, microwave attenuators, isolators, modulators, microwave switching devices, R-F microwave phase shifters, amplifiers, frequency multipliers and mixers.

Ferrites used for such applications are at the opposite end of the spectrum from those in which Hughes' sphere of interest lies. To date, Hughes has been concerned with microwave ferrite applications, the market for which is almost entirely military end-use. Three approaches have been utilized: the rotational approach — when the polarizing magnetic field is parallel to the propagation direction of the microwave field, the action of the ferrite "gyroscopes" is to twist the plane of polarization of the electro-magnetic wave. The resonance approach — when the polarizing magnetic field is at right angles or parallel to the propagation direction of the microwave field and adjusted so that the precessional frequency of the electronic "gyroscopes" is the same as that of the electromagnetic wave, then the ferrite material acts as a reciprocal or differential absorber. The phase-shift approach — when the polarizing magnetic field is at right angles to the propagation direction of the microwave field, but adjusted so that the precessional frequency of the electronic "gyroscopes" differs somewhat from that of the electromagnetic wave, then the ferrite material acts as a non-reciprocal phase shifter. These three approaches have resulted in several types of isolators, duplexers, switches and attenuators, which are being used in Hughes systems, as well as others.

THE DEVELOPMENT OF FERRITE DEVICES

Ferrites today are among the most fascinating of contemporary electronic products. Their history, however, is not limited to the past few years. The properties of ferrites were first recognized in 1909, but as in so many innovations, concerted research and development was not conducted until twenty four years later by the Philips Laboratory of Eindhoven, Holland. It was there that ferrites initially demonstrated excellent magnetic properties. In the U. S., basic studies on ferrites were accomplished at the Bell Telephone Laboratories. There, the interest was communication circuit application. Hughes entered the field during 1951 and subsequently directed its attention toward ferrites for high power, high frequency radar systems. The urgent demands occasioned by the development of highly advanced fire-control systems and missile production gave some clues to the potential of the ferro-magnetic materials. These systems were designed to incorporate microwave circuits which lent themselves especially well to the use of ferrite devices. Through application of the Faraday rotation and resonant absorption phenomena exhibited by ferrites at microwave frequencies, scientists and engineers have developed and built devices such as isolators, circulators, frequency modulators, microwave switches, and electronically controlled phase shifters and variable attenuators. Many of the new devices are for military applications, and many more are suitable for commercial utilization.

FUTURE FOR MICROWAVE FERRITE DEVICES

While many knowledgeable persons consider the present state of the ferrite art to be at about level of semiconductor art 6 to 8 years ago, great strides are being taken. Already S-band and X-band devices are coming into their own and devices for other frequencies are being developed. Ferrite circulators and switches are expected ultimately to replace TR-ATR gas tubes in both airborne and ground radar systems since they are more reliable and have an unlimited life. The commercial market for ferrite microwave devices in 1957 reached approximately the $4 million dollar mark. It is estimated that in 1958 sales will amount to $6½ million dollars and by 1961, of course depending upon the progress in many military communications systems, the sales should be in the neighborhood of $40 million dollars. Certain developments now afoot could easily boost this sales volume even higher. There are new types of panoramic radar systems now under study and it is foreseeable that if those systems are developed in sufficient time, the 1961 sales could reach $75 million dollars

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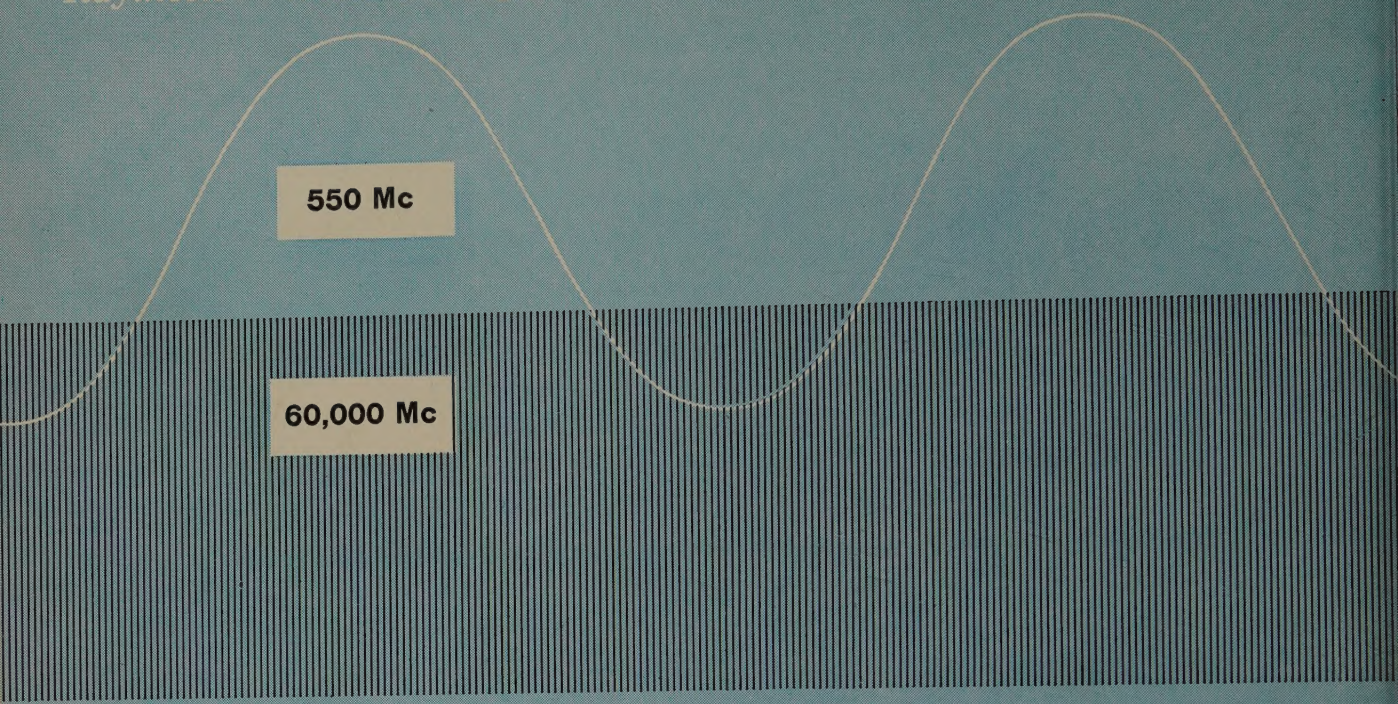

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3 TYPICAL RAYTHEON REFLEX KLYSTRONS

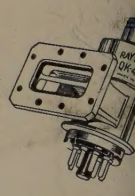
RK-5721 – Velocity variation oscillator designed for use with a coaxial cavity in CW or pulsed operation over the 4290 to 11,000 Mc range for signal generator and special local oscillator applications.

Heater Input @ 0.58 A	6.3 V
Reflector Voltage Transit Mode	2¾ cycles
Frequency Range	4290-8340 Mc
DC Resonator Input @ 20 mA	1000 Vdc
DC Reflector Voltage	-50 to -625 V
Electronic Tuning (Half Power) Frequency Change	12 Mc min.
Reflector Modulation Sensitivity (8340 Mc)	0.1 Mc/volt
Power Output (Average CW)	160 mW

RK-6116 – A ruggedized thermally tuned oscillator of the integral cavity type designed for CW operation in the 8500 to 9600 Mc range with an average power output of 30 mW.

Heater Input @ 0.52 A	6.3 V
Tuner Heater Current	0.80 A
Frequency Range	8500-9660 Mc
Resonator Input @ 25 mA	300 Vdc
Reflector Voltage (max. Po @ 8550 to 9660 Mc)	-60 to -145 Vdc
Thermal Tuning Time 8500-9660 Mc	2 seconds
Electronic Tuning Range @ 9080 Mc	100 Mc
Power Output 8500-9660 Mc	26 to 34 mW

QK-422–A mechanically tuned velocity variation oscillator designed for CW operation in the 7125 to 8125 Mc range in microwave relay systems.



Heater Input @ .44 A	6.3
Frequency Range	7125 to 8125 M
DC Resonator Input @ 32 mA	300 Vd
DC Reflector Voltage (max. Po @ 7125 to 8125 Mc)	-130 to -210 Vd
Power Output 7125 to 8125 Mc	140 m
Electronic Tuning (to half power points) @ 7600 Mc	28 M
Modulation Sensitivity @ 7600 Mc (10 V pk. to pk. mod. volt)	.5 Mc/

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